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A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Low-Gradient Riverine Wetlands in Western Tennessee

Timothy C. Wilder and Thomas H. Roberts

April 2002

Environmental Laboratory

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Wetlands Research Program

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A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Low-Gradient Riverine Wetlands in Western Tennessee

by Timothy C. Wilder

Tennessee Department of Environment and Conservation
Water Pollution Control
2484 Park Plus Drive
Columbia, TN 38401

Thomas H. Roberts

Tennessee Technological University
Biology Department
P.O. Box 5063
Cookeville, TN 38505

Final report

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Assessing Wetland Functions

A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Low-Gradient Riverine Wetlands in Western Tennessee (ERDC/EL TR-02-6)

ISSUE: Section 404 of the Clean Water Act directs the U.S. Army Corps of Engineers to administer a regulatory program for permitting the discharge of dredged or fill material in "waters of the United States." As part of the permit review process, the impact of discharging dredged or fill material on wetland functions must be assessed. On 16 August 1996 a National Action Plan to Implement the Hydrogeomorphic Approach (NAP) for developing Regional Guidebooks to assess wetland functions was published. This report is one of a series of Regional Guidebooks that will be published in accordance with the National Action Plan.

RESEARCH OBJECTIVE: The objective of this research was to develop a Regional Guidebook for assessing the functions of low-gradient riverine wetlands in western Tennessee in the context of the 404 Regulatory Program.

SUMMARY: The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The Approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including: determining minimal effects under the Food Security Act, designing mitigation projects, and managing wetlands. This report uses the HGM Approach to develop a Regional Guidebook for assessing the functions of low-gradient riverine wetlands in western Tennessee.

AVAILABILITY OF REPORT: The report is available at the following Web site: *http://www.wes.army.mil/el/wetlands/wlpubs.html.* The report is also available on Interlibrary Loan Service from the U.S. Army Engineer Research and Development Center (ERDC) Research Library, telephone (601) 634-2355, or the following Web site: *http://libweb.wes.army.mil/index.htm.*

About the Authors: Mr. Timothy C. Wilder, Tennessee Department of Environment and Conservation. Dr. Thomas H. Roberts, Tennessee Technological University.

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Preface

This Regional Guidebook was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Characterization and Restoration of Wetlands Research Program (CRWRP). It is published as an Operational Draft for field testing for a 2-year period. Comments should be submitted via the Internet at the following address: http://www.wes.army.mil/el/wetlands/hgmhp.html. Written comments should be addressed to: Department of the Army Engineer Research and Development Center, CEERD-EE-W, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199. The work was performed under Work Unit 32985, "Technical Development of HGM," for which Dr. Ellis J. Clairain, Jr., Environmental Laboratory (EL), Vicksburg, MS, U.S. Army Engineer Research and Development Center (ERDC), was the Principal Investigator. Mr. Dave Mathis, CERD-C, was the CRWRP Coordinator at the Directorate of Research and Development, HQUSACE; Ms. Colleen Charles, CECW-OR, served as the CRWRP Technical Monitor's Representative; Dr. Russell F. Theriot, EL, was the CRWRP Program Manager; and Dr. Clairain was the Task Area Manager. This document and study were funded through a Wetlands Protection State Development Grant by Region IV of the Environmental Protection Agency. Mr. Michael W. Lee was grant administrator for the Tennessee Department of Environment and Conservation.

This report was prepared by Mr. Timothy C. Wilder, Tennessee Department of Environment and Conservation, Columbia, TN, and Dr. Thomas H. Roberts, Tennessee Technological University, Cookeville, TN. Mr. Wilder and Dr. Roberts slightly modified the "Regional Guidebook for Assessing the Functions of Low-Gradient Riverine Wetlands in Western Kentucky" to adapt it for use in western Tennessee. This work took place under the general supervision of Dr. Morris Mauney, Chief, Wetlands and Coastal Ecology Branch, EL; Dr. Conrad Kirby, Chief, Environmental Resources Division, EL; and Dr. Edwin A. Theriot, Director, EL.

Persons making significant contributions to the Tennessee revision include the Assessment Team members: Ms. Patricia L. Coffey and Messrs. Ray D. Hedrick and K. Wade Whittinghill, U.S. Army Engineer District, Nashville; Mr. Timothy Davis, U.S. Army Engineer District, Memphis; Messrs. Daniel C. Eagar and Michael W. Lee, Tennessee Department of Environment and Conservation; Mr. Joe F. Hopper, Tennessee Wildlife Resources Agency;

Mr. Douglas Winford, U.S. Fish and Wildlife Service; and Mr. Michael E. Zeman, Natural Resources Conservation Service.

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At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

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1 Introduction

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including determining minimal effects under the Food Security Act, designing mitigation projects, and managing wetlands.

On 16 August 1996 a National Action Plan to Implement the Hydrogeomorphic Approach (NAP) was published (National Interagency Implementation Team 1996). The NAP was developed cooperatively by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highways Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). Publication of the NAP was designed to outline a strategy and promote the development of Regional Guidebooks for assessing the functions of regional wetland subclasses using the HGM Approach, to solicit the cooperation and participation of Federal, State, and local agencies, academia, and the private sector in this effort, and to update the status of Regional Guidebook development.

The sequence of tasks necessary to develop a Regional Guidebook outlined in the NAP was used to develop this Regional Guidebook (see Development Phase). The National Riverine Guidebook (Brinson et al. 1995) served as the starting point for an initial workshop held at Lake Barkley State Park, KY, on 21-24 May 1996. The workshop was attended by hydrologists, biogeochemists, soil scientists, wildlife biologists, and plant ecologists from the public, private, and academic sectors with extensive knowledge of riverine, low-gradient forested wetlands in western Tennessee and western Kentucky. Based on the results of the workshop, a regional wetland subclass was defined and characterized, reference domains in both states were defined, wetland functions were selected, model variables were identified, and conceptual assessment models were developed. Subsequently, field work was conducted to collect data from reference wetlands. These data were used to revise and calibrate the

conceptual assessment models. A draft version of this Regional Guidebook was then subjected to several rounds of peer review and revised into the present document. Work on the Kentucky Guidebook was completed in late 1998 and was published as an operational draft in May 1999 as WES Technical Report WRP- DE-17. This Guidebook is a companion document modified to make it applicable for use in western Tennessee. The functions, assessment models, and supporting materials are the same as in the western Kentucky Guidebook. The principal differences in the two documents are that in this report the models are scaled using data from western Tennessee reference wetlands and that Chapter 3 is a description of the western Tennessee reference domain. Some minor differences also exist in data collection procedures.

The objectives of this Regional Guidebook are to: (a) characterize the low-gradient riverine wetland systems in the western Tennessee reference domain, (b) provide the rationale used to select functions for the low-gradient riverine regional subclass, (c) provide the rationale used to select model variables and metrics, (d) provide the rationale used to develop assessment models, (e) provide data from reference wetlands used in calibrating model variables and assessment models, and (f) outline the necessary protocols for applying the functional indices to the assessment of wetland functions.

This document is organized in the following manner. Chapter 1 provides the background, objectives, and organization of the document. Chapter 2 provides an overview of the major components of the HGM Approach and the Development and Application Phases required to implement the approach. Chapter 3 characterizes the Low Gradient Riverine Subclass in western Tennessee in terms of geographical extent, climate, geomorphic setting, hydrology, vegetation, soils, and other factors that influence wetland function. Chapter 4 discusses each of the wetland functions, model variables, and functional indices. This discussion includes a definition of the function, a quantitative, independent measure of the function for the purposes of validation, a description of the wetland ecosystem and landscape characteristics that influence the function, a definition and description of model variables used to represent these characteristics in the assessment model, a discussion of the assessment model used to derive the functional index, and an explanation of the rationale used to calibrate the index with reference wetland data. Chapter 5 outlines the steps of the assessment protocol for conducting a functional assessment of low-gradient riverine wetlands in western Tennessee. Appendix A is a glossary of words and terms associated with wetland assessment. Appendix B provides summaries of functions, assessment models, variables, variable measures, and copies of the field forms used in data collection. Appendix C provides expanded discussions on how to measure selected assessment variables. Appendix D contains the data collected at reference wetlands.

While it is possible to assess the functions of low-gradient riverine wetlands in western Tennessee using only the information contained in Chapter 5 and Appendix B, it is suggested that potential users familiarize themselves with the information in Chapters 2-4 prior to conducting an assessment.

2 Overview of the Hydrogeomorphic Approach

As indicated in Chapter 1, the HGM Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The HGM Approach includes four integral components: (a) the HGM Classification, (b) reference wetlands, (c) assessment models/ functional indices, and (d) assessment protocols. During the Development Phase of the HGM Approach, these four components are integrated in a Regional Guidebook for assessing the functions of a regional wetland subclass. Subsequently, during the Application Phase, end users, following the assessment protocols outlined in the Regional Guidebook, assess the functional capacity of selected wetlands. Each of the components of the HGM Approach and the Development and Application Phases are discussed below. More extensive treatment of these topics can be found in Brinson (1993a,b; 1995a,b), Brinson et al. (1995, 1996, 1998), Smith et al. (1995), Hauer and Smith (1998), and Wetlands Research Program (WRP) (in preparation).

Hydrogeomorphic Classification

Wetland ecosystems share a number of common attributes including relatively long periods of inundation or saturation, hydrophytic vegetation, and hydric soils. In spite of these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and exhibit a wide range of physical, chemical, and biological characteristics and processes (Ferren, Fiedler, and Leidy 1996; Ferren et al. 1996a,b; Mitch and Gosselink 1993; Semeniuk 1987; Cowardin et al. 1979). The variability of wetlands makes it challenging to develop assessment methods that are both accurate (i.e., sensitive to significant changes in function) and practical (i.e., can be completed in the relatively short time frame available for conducting assessments). Existing "generic" methods, designed to assess multiple wetland types throughout the United States, are relatively rapid, but lack the resolution necessary to detect significant changes in function.

One way to achieve an appropriate level of resolution within the available time frame is to reduce the level of variability exhibited by the wetlands being considered (Smith et al. 1995). The HGM Classification was developed specifically to accomplish this task (Brinson 1993a). It identifies groups of wetlands that function similarly using three criteria that fundamentally influence how wetlands function. These criteria are geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the landform and position of the wetland in the landscape. Water source refers to the primary water source in the wetland such as precipitation, overbank floodwater, or groundwater. Hydrodynamics refers to the level of energy and the direction that water moves in the wetland. Based on these three criteria, any number of "functional" wetland groups can be identified at different spatial or temporal scales. For example, at a continental scale, Brinson (1993a,b) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 1 (Smith et al. 1995). In many cases, the level of variability in wetlands encompassed by a continental scale hydrogeomorphic class is still too great to develop assessment models that can be rapidly applied while being sensitive enough to detect changes in function at a level of resolution appropriate to the 404 review process. For example, at a continental geographic scale, the depression class includes wetlands as diverse as California vernal pools (Zedler 1987), prairie potholes in North and South Dakota (Kantrud, Krapu, and Swanson 1989; Hubbard 1988), playa lakes in the high plains of Texas (Bolen, Smith, and Schramm 1989), kettles in New England, and cypress domes in Florida (Kurz and Wagner 1953, Ewel and Odum 1984).

To reduce both inter- and intraregional variability, the three classification criteria are applied at a smaller regional geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (Stewart and Kantrud 1971; Golet and Larson 1974; Wharton et al. 1982; Ferren, Fiedler, and Leidy 1996; Ferren et al. 1996a,b). Regional subclasses, like the continental classes, are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. In addition, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain regions. For example, depression subclasses might be based on water source (i.e., groundwater versus surface water) or the degree of connection between the wetland and other surface waters (i.e., the flow of surface water into or out of the depression through defined channels). Tidal fringe subclasses might be based on salinity gradients (Shafer and Yozzo 1998). Slope subclasses might be based on the degree of slope, landscape position, source of water (i.e., throughflow versus groundwater), or other factors. Riverine subclasses might be based on water source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 2, Smith et al. (1995), and Rheinhardt, Brinson, and Farley (1997).

Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of its geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process.

Table 1
Hydrogeomorphic Wetland Classes at the Continental Scale

HGM Wetland Class	Definition
Depression	Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater/ interflow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression. The predominant hydrodynamics are vertical fluctuations that range from diurnal to seasonal. Depression wetlands may lose water through evapotranspiration, intermittent or perennial outlets, or recharge to groundwater. Prairie potholes, playa lakes, vernal pools, and cypress domes are common examples of depression wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal current diminishes and riverflow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine classes is where bidirectional flows from tides dominate over unidirectional ones controlled by floodplain slope of riverine wetlands. Because tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. *Spartina alterniflora* salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. In some cases, these wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional, usually controlled by water-level fluctuations resulting from wind or seiche. Lacustrine wetlands lose water by flow returning to the lake after flooding and evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.
Slope	Slope wetlands are found in association with the discharge of groundwater to the land surface or sites with saturated overland flow with no channel formation. They normally occur on sloping land ranging from slight to steep. The predominant source of water is groundwater or interflow discharging at the land surface. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, surface flows, and evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands.
Mineral Soil Flats	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. They typically occur in relatively humid climates. Pine flatwoods with hydric soils are an example of mineral soil flat wetlands.

(Continued)

Table 1 (Concluded)	
HGM Wetland Class	**Definition**
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are examples of organic soil flat wetlands.
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In headwaters, riverine wetlands often intergrade with slope, depressional, poorly drained flat wetlands, or uplands as the channel (bed) and bank disappear. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evapotranspiration. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long periods of saturation from groundwater sources. Bottomland hardwoods on floodplains are an example of riverine wetlands.

Table 2
Potential Regional Wetland Subclasses in Relation to Geomorphic Setting, Dominant Water Source, and Hydrodynamics

Geomorphic Setting	Dominant Water Source	Dominant Hydrodynamics	Potential Regional Wetland Subclasses	
			Eastern USA	**Western USA/Alaska**
Depression	Groundwater or interflow	Vertical	Prairie pothole marshes, Carolina bays	California vernal pools
Fringe (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake marshes
Slope	Groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (organic soil)	Precipitation	Vertical	Peat bogs; portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizontal	Bottomland hardwood forests	Riparian wetlands

Reference Wetlands

Reference wetlands are the wetland sites selected to represent the range of variability that occurs in a regional wetland subclass as a result of natural processes and disturbance (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as cultural alteration. The reference domain is the geographic area occupied by the reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the reference domain will mirror the geographic area encompassed by the regional wetland subclass; however, this is not always possible due to time and resource constraints.

Reference wetlands serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of function across the suite of functions selected for a regional wetland subclass. Second, they establish the range and variability of conditions exhibited by model variables and provide the data necessary for calibrating model variables and assessment models. Finally, they provide a concrete physical representation of wetland ecosystems that can be repeatedly observed and measured.

Reference standard wetlands are the subset of reference wetlands that perform the suite of functions selected for the regional subclass at a level that is characteristic in the least altered wetland sites in the least altered landscapes. Table 3 outlines the terms used by the HGM Approach in the context of reference wetlands.

Table 3
Reference Wetland Terms and Definitions

Term	Definition
Reference domain	The geographic area from which reference wetlands representing the regional wetland subclass are selected (Smith et al. 1995).
Reference wetlands	A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and disturbance and from human alteration.
Reference standard wetlands	The subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human altered wetland sites in the least human altered landscapes. By definition, the functional capacity index score for all functions in reference standard wetlands is 1.0.
Reference standard wetland variable condition	The range of conditions exhibited by model variables in reference standard wetlands. By definition, reference standard conditions receive a variable subindex score of 1.0.
Site potential (mitigation project context)	The highest level of function possible, given local constraints of disturbance history, land use, or other factors. Site potential may be less than or equal to the levels of function in reference standard wetlands of the regional wetland subclass.
Project target (mitigation project context)	The level of function identified or negotiated for a restoration or creation project.
Project standards (mitigation context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

Assessment Models and Functional Indices

In the HGM Approach, an assessment model is a simple representation of a function performed by a wetland ecosystem. It defines the relationship between one or more characteristics or processes of the wetland ecosystem or surrounding landscape and the functional capacity of a wetland ecosystem. Functional capacity is simply the ability of a wetland to perform a function compared to the level of performance in reference standard wetlands.

Model variables represent the characteristics of the wetland ecosystem and surrounding landscape that influence the capacity of a wetland ecosystem to perform a function. Model variables are ecological quantities that consist of five components (Schneider 1994). These include: (a) a name, (b) a symbol, (c) a measure of the variable and procedural statement for quantifying or qualifying the measure directly or calculating it from other measurements, (d) a set of values (i.e., numbers, categories, or numerical estimates (Leibowitz and Hyman in preparation)) that are generated by applying the procedural statement, and (e) units on the appropriate measurement scale. Table 4 provides several examples.

Table 4
Components of a Model Variable

Name (Symbol)	Measure / Procedural Statement	Resulting Values	Units (Scale)
Redoximorphic Features (V_{REDOX})	Status of redoximorphic features/visual inspection of soil profile for redoximorphic features	present absent	unitless (nominal scale)
Floodplain Roughness (V_{ROUGH})	Manning's Roughness Coefficient (*n*) Observe wet-land characteristics to determine adjustment values for roughness component to add to base value	0.01 0.1 0.21	unitless (interval scale)
Tree Biomass (V_{TBA})	Tree basal area/measure diameter of trees in sample plots (cm), convert to area (m^2), and extrapolate to per hectare basis	5 12.8 36	m^2/ha (ratio scale)

Model variables occur in a variety of states or conditions in reference wetlands. The state or condition of the variable is denoted by the value of the measure of the variable. For example, tree basal area, the measure of the tree biomass variable could be large or small. Similarly, recurrence interval, the measure of overbank flood frequency variable, could be frequent or infrequent. Based on its condition (i.e., value of the metric), model variables are assigned a variable subindex. When the condition of a variable is within the range of conditions exhibited by reference standard wetlands, a variable subindex of 1.0 is assigned. As the condition deflects from the reference standard condition (i.e., the range of conditions that the variable occurs in reference standard wetland), the variable subindex is assigned based on the defined relationship between model variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard wetlands, it receives a progressively lower subindex reflecting its decreasing contribution to functional capacity. In some cases, the variable subindex drops to zero. For

example, when no trees are present, the subindex for tree basal area is zero. In other cases, the subindex for a variable never drops to zero. For example, regardless of the condition of a site, Manning's Roughness Coefficient (n) will always be greater than zero.

Model variables are combined in an assessment model to produce a Functional Capacity Index (FCI) that ranges from 0.0 - 1.0. The FCI is a measure of the functional capacity of a wetland relative to reference standard wetlands in the reference domain. Wetlands with an FCI of 1.0 perform the function at a level that is characteristic of reference standard wetlands. As the FCI decreases, it indicates the capacity of the wetland to perform the function is less than that which is characteristic of reference standard wetlands.

Assessment Protocol

The final component of the HGM Approach is the assessment protocol. The assessment protocol is a series of tasks, along with specific instructions, that allow the end user to assess the functions of a particular wetland area using the functional indices in the Regional Guidebook. The first task is characterization which involves describing the wetland ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the wetland areas to be assessed. The second task is collecting the field data for model variables. The final task is analysis which involves calculation of functional indices.

Development Phase

The Development Phase of the HGM Approach is ideally carried out by an interdisciplinary team of experts known as the "Assessment Team," or "A-Team." The product of the Development Phase is a Regional Guidebook for assessing the functions of a specific regional wetland subclass (Figure 1). In developing a Regional Guidebook, the A-Team will complete the following major tasks. After organization and training, the first task of the A-Team is to classify the wetlands within the region of interest into regional wetland subclasses using the principles and criteria of the Hydrogeomorphic Classification (Brinson 1993a; Smith et al. 1995). Next, focusing on the specific regional wetland subclass selected, the A-Team develops an ecological characterization or functional profile of the subclass. The A-Team then identifies the important wetland functions, conceptualizes assessment models, identifies model variables to represent the characteristics and processes that influence each function, and defines metrics for quantifying model variables. Next, reference wetlands are identified to represent the range of variability exhibited by the regional subclass. Field data are then collected from the reference wetlands and used to calibrate model variables and verify the conceptual assessment models. Finally, the A-Team develops the assessment protocols necessary for regulators, managers,

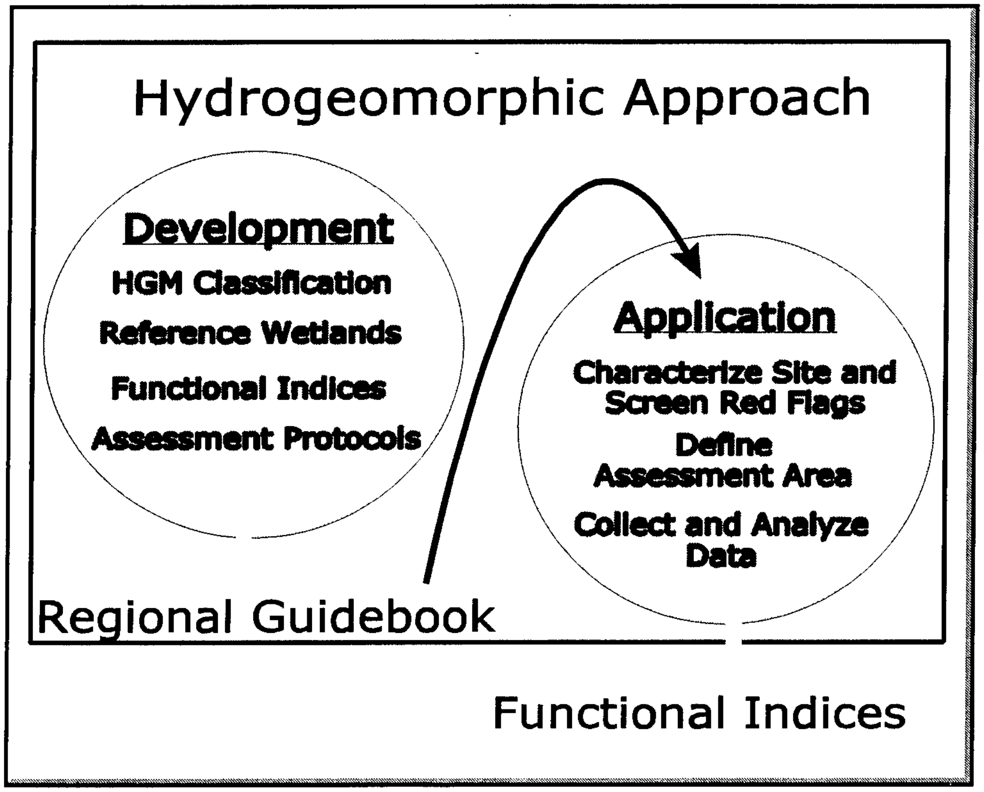

Figure 1. Development and application phases of the HGM Approach

consultants, and other end users to apply the indices to the assessment of wetland functions. The following list provides the detailed steps involved in the general sequence described above.

Task 1: Organize the A-Team
- A. Identify A-Team members
- B. Train A-Team in the HGM Approach

Task 2: Select and Characterize Regional Wetland Subclass
- A. Identify/prioritize regional wetland subclasses
- B. Select regional wetland subclass and define reference domain
- C. Initiate literature review
- D. Develop preliminary characterization of regional wetland subclass
- E. Identify and define wetland functions

Task 3: Select Model Variables and Metrics and Construct Conceptual Assessment Models
- A. Review existing assessment models
- B. Identify model variables and metrics
- C. Define initial relationship between model variables and functional capacity

D. Construct conceptual assessment models for deriving functional capacity indices (FCI)
E. Complete Precalibrated Draft Regional Guidebook (PDRG)

Task 4: Conduct Peer Review of PDRG
A. Distribute PDRG to peer reviewers
B. Conduct interdisciplinary, interagency workshop of PDRG
C. Revise PDRG to reflect peer review recommendations
D. Distribute revised PDRG to peer reviewers for comment
E. Incorporate final comments from peer reviewers on revisions into the PDRG

Task 5: Identify and Collect Data From Reference Wetlands
A. Identify reference wetland field sites
B. Collect data from reference wetland field sites
C. Analyze reference wetland data

Task 6: Calibrate and Field Test Assessment Models
A. Calibrate model variables using reference wetland data
B. Verify and validate (optional) assessment models
C. Field test assessment models for repeatability and accuracy
D. Revise PDRG based on calibration, verification, validation (optional), and field testing results into a Calibrated Draft Regional Guidebook (CDRG)

Task 7: Conduct Peer Review and Field Test of CDRG
A. Distribute CDRG to peer reviewers
B. Field test CDRG
C. Revise CDRG to reflect peer review and field test recommendations
D. Distribute CDRG to peer reviewers for final comment on revisions
E. Incorporate peer review final comments on revisions
F. Publish Operational Draft Regional Guidebook (ODRG)

Task 8: Technology Transfer
A. Train end users in the use of the ODRG
B. Provide continuing technical assistance to end users of the ODRG

Application Phase

The Application Phase involves two steps. The first is using the assessment protocols outlined in the Regional Guidebook to carry out the following tasks (Figure 1).

a. Define assessment objectives

b. Characterize the project site

c. Screen for red flags

d. Define the Wetland Assessment Area

e. Collect field data

f. Analyze field data

The second step involves applying the results of the assessment, the FCI, to the appropriate decision making processes of the permit review sequence, such as alternatives analysis, minimization, assessment of unavoidable impacts, determination of compensatory mitigation, design and monitoring of mitigation, comparison of wetland management alternatives or results, determination of restoration potential, or identification of acquisition or mitigation sites.

3 Characterization of Low-Gradient Riverine Wetlands in Western Tennessee

Regional Wetland Subclass and Reference Domain

This Regional Guidebook was developed to assess the functions of frequently flooded, forested wetlands on floodplains of low gradient rivers. These wetlands are known locally, and throughout much of the southeastern United States, as bottomland hardwoods (Wharton et al. 1982). Exact estimates of the acreage of this type of wetland in Tennessee are lacking, but an average of several data sources including the National Wetland Inventory (Hefner and Brown 1984) and the USDA National Resource Inventory (USDA Soil Conservation Service 1987) indicated that there are 814,000 acres of palustrine wetlands in Tennessee with the majority occurring in the western portion of the state (Tennessee Department of Conservation 1988) (Figure 2). Most of these wetlands are classified as palustrine forested (PFO) (Cowardin et al. 1979) and would be considered to be within the HGM low gradient riverine regional subclass.

According to Smith et al. (1995), the reference domain is the geographic area occupied by the reference wetland sites. Under ideal circumstances, the reference domain that is used to develop a Regional Guidebook will mirror the full geographic extent of the regional wetland subclass. It was not possible, however, to sample reference wetlands throughout the range of the subclass, thus the reference domain within which these models are applicable represents a geographic subset of the regional subclass.

The reference domain for which this guidebook was developed is the Loess Plains ecoregion of western Tennessee; one of the four ecoregions in that portion of the state that were defined and described by Griffith, Omernik, and Azevedo (1997) (Figure 2). The Loess Plains is an area of relatively little relief, varying from nearly level to gently rolling. Numerous tributaries to the Mississippi

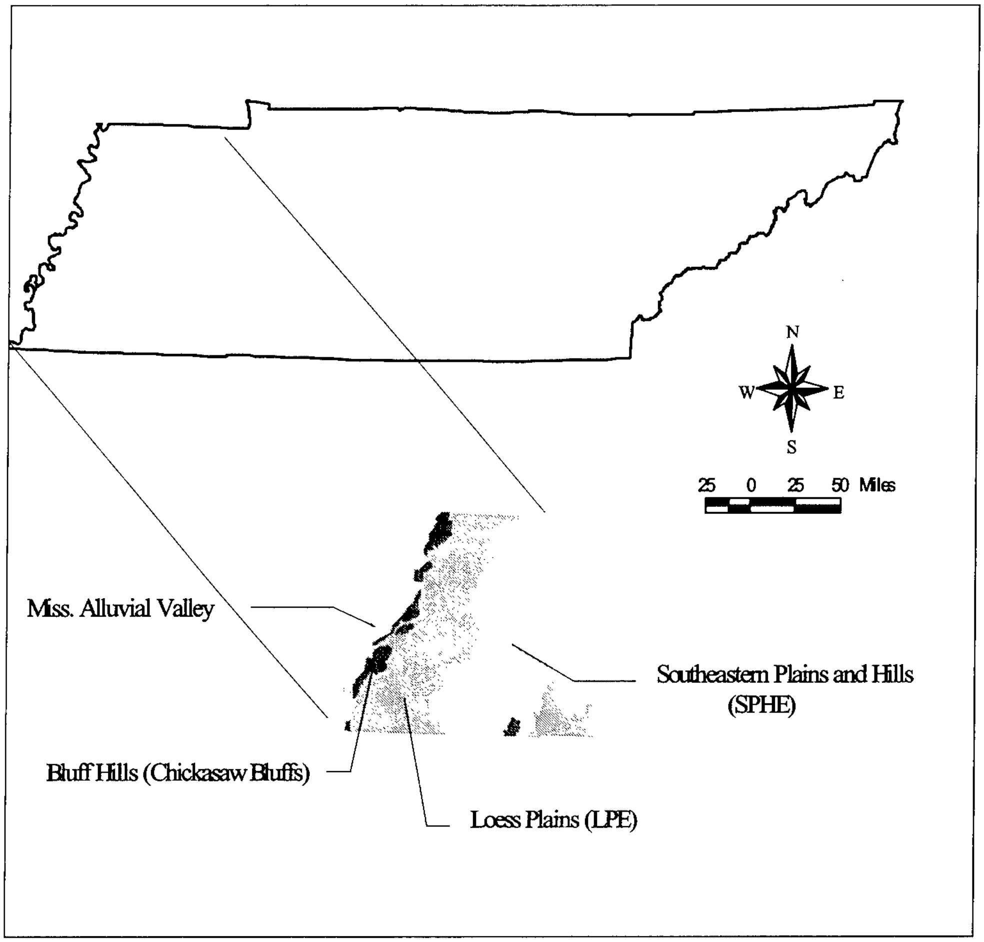

Figure 2. Ecoregions of western Tennessee (from Griffith, Omernik, and Azevedo 1997)

River (the Obion, Forked Deer, Hatchie, Loosahatchie, and Wolf Rivers) cross the region. The rivers themselves have sand and silt bottoms and floodplains that are wide and flat. Historically the rivers had a slope of less than 0.066 percent and meandered through straight valleys (Ashley 1910b). Most of the ecoregion has been cleared and converted to the production of row crops. Some extensive forested tracts still remain on state and federal lands and on lands owned by timber companies.

The other three ecoregions of western Tennessee (described in the next paragraph) were not included in the development of the data set used to scale the models presented in this guidebook. They are, however, generally similar in nature and include numerous wetlands within the low gradient riverine regional subclass. With additional data collection, it is believed that the models presented in this guidebook would be appropriate for use in those ecoregions as well.

The westernmost ecoregion in Tennessee is the Mississippi Alluvial Valley, the active floodplain of the Mississippi River. This ecoregion is characterized by level topography with river terraces and levees providing the only topographical relief. Oxbow lakes and swamps are relatively common. Streams are low gradient. Eastward of the Mississippi Alluvial Valley is the narrow band of the Bluff Hills (sometimes referred to as the Chickasaw Bluffs) where loess deposits are very thick, extending to depths of between 10 and 30 m. It is an area of irregular plains with dissected hills and ridges. Streams are moderate to low gradient. The fourth ecoregion in western Tennessee, the Southeastern Plains and Hills, has more varied topography than the others; hills are steeper than in the Loess Plains ecoregion and the streams have a higher gradient. At the eastern edge of this ecoregion, the loess may be less than 1 m thick.

Description of the Regional Subclass

Rivers are the features that are responsible for the formation and maintenance of wetlands within the low-gradient riverine subclass. They are constantly reworking the floodplain sediments (Sigafoos 1964, Hey 1978), primarily by lateral migration (Shelford 1954; Sigafoos 1964; Wharton et al. 1982; Shankman and Drake 1990; Shankman 1991, 1993). Rivers deposit sediments eroded from the floodplain and channel banks on the convex side of the river, resulting in point bar accretion (Sigafoos 1964, Keller 1972, Hey 1978, Wharton et al. 1982, Shankman 1991). The result is that most of the sediment stays in the floodplain (Sigafoos 1964). In this manner, the river reworks the floodplain alluvium to the depth of its channel and over geologic time meanders back and forth across its valley (Sigafoos 1964, Shankman 1993). The mechanisms by which sediment is reworked, in order of importance, are: (a) lateral migration, (b) local scour and deposition, and (c) vertical accretion (Sigafoos 1964). The overall result of these fluvial processes is a complex mosaic of features varying in texture and hydrologic regime and generally progressing in age and elevation as distance from the channel increases (Shelford 1954; Sigafoos 1964; Bedinger 1979, 1981; Shankman 1993). Following is an overview of the processes that created the features that exist within most low gradient riverine systems.

As a river meanders, parts of the channel are cut off, forming oxbow lakes (Bedinger 1981, Shankman 1993). Also, as the channel migrates away from point bars, younger point bar surfaces begin to build on the channelward side. This results in scroll marks, alternating ridges of coarse, highly permeable sediment and intervening swales where fine, relatively impermeable sediments accumulate (Wharton et al. 1982). In addition, overbank flow deposits the coarsest sediments, such as sand, as it leaves the channel (Bedinger 1981, Wharton et al. 1982). This forms natural levees which are usually the highest features of the active floodplain (Bedinger 1981, Wharton et al. 1982). These geomorphic surfaces are evident on most major river systems in the low gradient subclass, although in relatively unaltered systems, they are constantly in a state of change. As floodwaters move across the floodplain, scouring occurs locally where flow is concentrated by vegetation, debris, etc., and sediment deposition occurs in the slack water areas. When the floods recede, the finest sediments are

trapped in ponded areas, sloughs, oxbow lakes, and beaver ponds and eventually settle out, albeit very slowly (Shelford 1954, Sigafoos 1964, Bedinger 1981, Wharton et al. 1982). This steady vertical accretion of sediments eventually causes the older features to become less distinct; thus, floodplains tend to remain broad and relatively flat (Bedinger 1979, Wharton et al. 1982).

River channel morphology is a product of its range of discharges, valley slope, and nature of its sediment supply (Hey 1978, Bedinger 1981, Wharton et al. 1982). If changes occur in channel slope, discharge, or sediment supply (quantity or particle size), then the river will readjust its morphology to accommodate the change (Hey 1978, Rosgen 1996). If left in a natural condition, the river will achieve a steady state where it is neither aggrading nor degrading and the energy of the flowing water is expended as uniformly as possible (Hey 1978, Wharton et al. 1982, Rosgen 1996).

The hydrologic regime on a particular part of a floodplain is related to its age and elevation (Shelford 1954; Sigafoos 1964; Bedinger 1971, 1979, 1981; Shankman 1993) however, and there is considerable variation among various portions of the floodplain. For example, the oldest and highest features of the floodplain, the terraces or relict floodplain surfaces, flood least frequently and for very short duration, if at all (Bedinger 1971, Wharton et al. 1982). Point bars are the youngest features and are lowest in elevation. Consequently, they are inundated most frequently and for the longest duration (Shelford 1954). The frequency and duration of flooding of other portions of the floodplain range between these two extremes. These features, listed in order from least frequently inundated to most frequently inundated, are natural levees, flats, scour pools and channels, sloughs, beaver ponds, and oxbows (Bedinger 1981, Wharton et al. 1982).

Groundwater dynamics

The depth to the groundwater table in low gradient riverine wetlands is related to the distance from the channel. It is lowest immediately adjacent to the channel (Maki et al. 1980, Bedinger 1981). Other surface features such as oxbow lakes and tributary channels also affect the groundwater table, as they serve as discharge areas during dry periods (Bedinger 1981). The alluvium underlying the floodplain contains the near-surface aquifer that interacts with the river and the other surface water features of the floodplain. Exchange with the deeper aquifers in the underlying strata is minor, however, compared with the volume of flow within the floodplain alluvium (Bedinger 1981).

The groundwater table fluctuates seasonally, recharging in winter and early spring through the permeable areas of the floodplain when overbank flow occurs (Bedinger 1981). During the dry time of year, the near-surface aquifers provide the base flow of the river (Maki et al. 1980, Bedinger 1981). The floodplain aquifer probably is very important to the plant community that develops on the floodplain (Maki et al. 1980, Bedinger 1981), although studies of the relationship are uncommon.

Bottomland hardwood forests

In low gradient riverine systems in the Southeast, floodplains are dominated by a forest community generally referred to as bottomland hardwoods (BLH). Wharton et al. (1982) described five ecological "zones" (Table 5) based on floodplain features and the associated soil and hydrologic conditions. The conditions that prevail within these zones, especially soil oxygen availability during the growing season, control which plant species become dominant (Wharton et al. 1982, Theriot 1993). Wharton et al. (1982) described 75 communities within the respective zones of the floodplain. Many of the types, however, occur only in the Atlantic and Gulf Coastal Plain, not in western Tennessee. Examples of these include live oak (*Q. virginiana*) and cabbage palm (*Sabal palmetto*).

The primary natural disturbance mechanism that shapes BLH forests in riverine systems is channel migration (Shankman 1993). Surfaces of varying age, elevation, texture, and hydrologic regime are the result of rivers moving back and forth across their floodplains (Shelford 1954; Sigafoos 1964; Bedinger 1971, 1979, 1981; Patrick 1981; Wharton et al. 1982; Junk, Bayley, and Sparks 1989, Shankman 1993). These surfaces have complex combinations of environmental gradients to which the plant species of BLHs respond individually (Shelford 1954, Sigafoos 1964, Wharton and Brinson 1978, Bedinger 1979, Fredrickson 1979, White 1979, Wharton 1980, Huffman and Forsythe 1981, McKnight et al. 1981, Junk, Bayley, and Sparks 1989, Shankman and Drake 1990, Shankman 1991).

Individual species respond to these gradients according to their physiology and genetics. Some tolerate a wider range of site conditions than others, causing overlap among communities on the floodplain (Teskey and Hinckley 1977, Bedinger 1979). Distinct assemblages, however, are recognizable along the hydrologic gradients (Bedinger 1979), and it is the dominants that allow separation of one community from another (Teskey and Hinckley 1977).

The most important of these environmental gradients is that reflecting the hydrologic regime (Shelford 1954; Sigafoos 1964; Bedinger 1971, 1979, 1981; Teskey and Hinckley 1977; White 1979; Huffman and Forsythe 1981; McKnight et al. 1981; Junk, Bayley, and Sparks 1989). The tolerance of seeds to periods of inundation, their requirements for germination, and their tolerance of submergence, sedimentation, and shade are what determine the composition of BLHs (McDermott 1954, Shelford 1954, Teskey and Hinckley 1977, Bedinger 1979, McKnight et al. 1981, Shankman and Drake 1990, Shankman and Kortright 1994). Texture and fertility of soil add complexity, but they are of secondary importance (Teskey and Hinckley 1977; White 1979; Bedinger 1981; Patrick 1981; Huffman and Forsythe 1981; Junk, Bayley, and Sparks 1989). Generally, tree diversity increases with decreasing flooding frequency, as relatively few species are tolerant of conditions in the wettest areas on the floodplain (Fredrickson 1979, McKnight et al. 1981).

Table 5
Characteristics of Floodplain Zones[1]

Characteristics	Zones: Depressions II	Depressions III	Flats IV	Flats V	Ridges VI
Degree of inundation and saturation	Intermittently exposed; nearly permanent inundation and saturation	Semipermanently inundated or saturated	Seasonally inundated or saturated	Temporarily inundated or saturated	Intermittently inundated or saturated
Timing of flooding	Year-round except during extreme droughts	Spring and summer during most of the growing season	Spring for 1-2 months of the growing season	Periodically for up to 1 month of the growing season	During exceptionally high floods or extreme wet periods
Probability of annual flooding	100%	51%-100%	51%-100%	10%-50%	1%-20%
Duration of flooding	100% of the growing season	>25% of the growing season	12.5%-25% of the growing season	2%-12.5% of the growing season	<2% of the growing season
Soil texture	Dominated by silty clays or loams	Dominated by dense clays	Clays dominate surface; some coarser fractions (sands) increase with depth	Clay and sandy loams dominate; sandy soils frequent	Sands to clays
Oxygenation	Moving water aerobic; stagnant water anaerobic	Anaerobic for portions of the year	Alternating anaerobic and aerobic conditions	Alternating: mostly aerobic, occasionally anaerobic	Aerobic year-round

[1] Source: Wharton et al. 1982.

The seasonal fluctuations of the groundwater table also are important in controlling species distribution (Maki et al. 1980, Bedinger 1981). McDermott (1954) found that tree seedlings of different species had variable tolerances for root zone saturation and the resulting stresses of anaerobic conditions. Flooding in BLHs mainly occurs during the dormant season, and inundation during this time has little or no effect on tree mortality, regardless of the duration (Bedinger 1979). The significance of flooding to the forest community may lie in its effect on the groundwater table (Bedinger 1981) that remains high during most of the growing season in unchannelized rivers (Maki et al. 1980).

Bottomland hardwood communities/succession

When point bars emerge, they initially are colonized by black willows (*Salix nigra*) and later by silver maple (*Acer saccharinum*) and cottonwood (*Populus deltoides*) (Shelford 1954, Teskey and Hinckley 1977). This seral stage is

followed in a few decades as the site rises and dries with dominance by overcup oak (*Quercus lyrata*), water hickory (*Carya aquatica*), green ash (*Fraxinus pennsylvanica*), persimmon (*Diospyros virginiana*), sugarberry (*Celtis laevigata*), and water locust (*Gleditsia aquatica*) (Shelford 1954, Teskey and Hinckley 1977, Shankman 1993). Many possible combinations of dominants could occur in the next seral stages (Teskey and Hinckley 1977, Hodges 1997). For example, the area may be scoured such that water ponds in subsequent years, or conversely, coarse sediments may continue to accumulate. The species that dominate may include swamp-chestnut oak (*Q. michauxii*), sweetgum (*Liquidambar styraciflua*), green ash, and hackberry (*C. occidentalis*) (Shelford 1954, Shankman 1993). The oldest and driest sites may be dominated by American beech (*Fagus grandifolia*), cherrybark oak (*Q. pagodifolia*), and water oak (*Q. nigra*) (Shankman 1993).

The early colonizers of point bars have several characteristics: seeds which remain viable after relatively long periods of inundation, seeds which are produced in great quantity in early spring when flooding is likely, seedlings which are tolerant of inundation and high rates of sedimentation and are intolerant of shade; seedlings which sprout easily if damaged and have lifespans that are short compared with other floodplain species (Shankman 1991, 1993). Species following the early colonizers are more tolerant of shade and also are tolerant of frequent, prolonged inundation and high rates of sedimentation. They are longer lived and dominate sites within a few decades after decline of the earliest colonizers. As the site rises with vertical accretion, flooding diminishes and other species not so tolerant of flooding may become established (Shelford 1954; Bedinger 1981; Shankman 1991, 1993).

Human alterations to rivers, floodplains, and the landscape

In low gradient river systems subject to extensive seasonal flooding, the object of channelization commonly is the reduction in the frequency, duration, and depth of inundation so that the valleys may be "reclaimed" for agriculture (Hidinger and Morgan 1912). This goal has been pursued throughout the Southeast (Arner et al. 1976, Kuenzler et al. 1977, Fredrickson 1979, Maki et al. 1980), and many of the streams and rivers in the low gradient riverine subclass have been altered dramatically. While flood reduction has occurred sometimes, results have not always been predictable. For example, in western Tennessee, frequency and duration of flooding were reduced in the upper Obion River and its forks by channelization; however, there was a 60 percent reduction in flood-wave travel time, and the runoff that converged on downstream areas increased both the frequency and magnitude of flood events there (Shankman and Pugh 1992). Similarly, channelization can increase the duration of flooding or ponding in an adjacent wetland due to spoil banks operating as artificial levees which prevent water from receding back into the channel. In both cases, the surface and subsurface hydroperiod of adjacent wetlands is altered which consequently affects hydrologic, biogeochemical, and habitat functions. Following is an overview of effects of alterations to low gradient rivers and their associated wetlands.

The most obvious and immediate results of channelization of Coastal Plain rivers are those changes immediately imposed on the river. Channels are straightened, deepened, widened, and cleared of obstructions, thus the resistance to flow (i.e. channel roughness) is reduced. Often, the length of the channel is shortened dramatically and its gradient is steepened. The desired effect is increased channel capacity that (in that reach of the river) reduces the frequency and duration of flooding (Robbins and Simon 1982).

Coastal Plain rivers begin responding immediately to the imposed morphology (Hey 1978, Rosgen 1996). The streambed upstream of the channelized reach is eroded due to the steepened gradient and consequent increase of energy and erosive power (Robbins and Simon 1982). This progressive degradation upstream decreases the bed slope and elevation and is known as a headcut. Concurrently, the relative height of the stream banks is increased. When the critical height and angle of the bank material is exceeded, it fails and slumps into the stream. This is known as mass wasting and results in the widening of the stream channel (Simon and Hupp 1987). Water velocities decrease in downstream unchannelized areas, especially where the river's grade is controlled where it enters another river. In these reaches, the transporting power of the channelized stream is reduced and sediments are deposited, resulting in aggradation (Robbins and Simon 1982, Simon and Robbins 1987).

If the imposed dimensions of a channelized reach are not maintained, the initially degrading areas begin aggrading after 10 to 15 years, and aggradation proceeds upstream (Shankman and Samson 1991, Shankman and Pugh 1992, Simon and Hupp 1992). The stream begins to recover its meandering nature by forming point bars, especially where mass wasting has increased channel width (Simon and Hupp 1987, 1992).

The greater relative depth of channelized streams probably increases the proportion of groundwater discharged into streams during periods of low flow (Kuenzler et al. 1977). This undoubtedly contributes to flow maintenance in some channelized streams during the summer and early fall (Kuenzler et al. 1977). Groundwater levels are reduced, especially in the vicinity of deepened channels and drainage ditches cut across the floodplain (Kuenzler et al. 1977, Maki et al. 1980, Bedinger 1981). In one study, depths to groundwater were more than 50 cm greater in floodplains adjacent to channelized rivers than they were in the floodplains of unchannelized rivers, and clear perennial flow was observed in the channelized streams, an indication of the channels interception of the water table (Maki et al. 1980). One effect of this alteration of groundwater levels by channelized rivers is an increase in storage capacity of the floodplain alluvium (Kuenzler et al. 1977, Maki et al. 1980). Evidence of this was found in North Carolina where flooding from small and medium rainstorms was reduced (Kuenzler et al. 1977) and virtually no inundation or ponding occurred on the floodplains of channelized streams (Maki et al. 1980).

The changes to the flooding regime and watertable after channelization affect the plant community of the floodplain (Fredrickson 1979, Maki et al. 1980, Bedinger 1981). Lowered watertables and decreased flooding allow mesic

species to compete with those adapted to more hydric conditions (Fredrickson 1979, Maki et al. 1980). Initially, a more mesic understory can develop on channelized streams beneath a more hydric overstory (Maki et al. 1980). Maki et al. (1980) found decreased survival of water tupelo (*Nyssa aquatica*) seedlings that they planted in channelized areas compared with those they had planted in other natural areas. They also found that when overstory established prior to channelization is removed, early successional herbaceous species and woody vines grew in profusion, out-competing most tree seedlings. In areas that had not been cut on channelized rivers, they observed a more dense and mesic understory.

Animals associated with aquatic habitats (e.g., fish, mammals such as beaver (*Castor canadensis*) and muskrat (*Ondatra zibethicus*), benthic and littoral macroinvertebrates, and amphibians in particular) were less abundant in channelized reaches (Arner et al. 1976, Maki et al. 1980). Herons and waterfowl were absent from channelized reaches of the St. Francis River in southeastern Missouri, and channelization there also had negative impacts on the distribution and abundance of invertebrates (Fredrickson 1979).

Many of the effects of channelization to riverine systems are subtle (such as the elimination of soil nourishment from overbank flooding), but some are obvious and significant. One is the degradation of water quality due to increased levels of phosphorous, inorganic nitrogen, and higher water turbidity (Arner et al. 1976, Kuenzler et al. 1977). Additionally, low levels of organic matter have been found in channelized streams (0 to 0.56 percent) compared to that found in unchannelized streams (0.55 to 1.91 percent) (Arner et al. 1976). Often overlooked, but possibly the most significant impact of channelization over time (if the artificial channel is maintained) is that the primary disturbance mechanism has been eliminated (Shankman 1993). Oxbows and erosional and depositional features no longer will be created. The more hydric species, especially baldcypress (*Taxodium distichum*) and others adapted to these floodplain features probably will decline (Shankman 1993). The floodplain may become drier and a more homogenous forest characteristic of higher floodplain zones or uplands is likely to result (Fredrickson 1979, Maki et al. 1980).

Description of the Reference Domain

Physiography and geology

The western third of Tennessee is part of the Mississippi Embayment of the Gulf Coastal Plain (Wells 1933). This area was covered by a sea during the first half of the Paleozoic Era. The sea retreated when a period of uplift began at the last half of the Paleozoic and continued through the end of the Mesozoic Era (Wells 1933, Miller 1974, Luther 1977). Eventually, the uplift ended as the area was eroded to a nearly featureless plain (Luther 1977). The earth's crust in the area began to sag during the Cretaceous period, and the sea again invaded, thereby forming an arm of the Gulf of Mexico known as the Mississippi

Embayment (Wells 1933, Miller 1974, Luther 1977). The sea covered western Tennessee well into the Tertiary period. The Paleozoic rocks of the area are buried to depths exceeding 900 m at Memphis, and the depth of sediments decreases to the east and west of Memphis by approximately 3 to 6 m per kilometers (Wells 1933, Miller 1974, Luther 1977). The edges of the Mississippi Embayment are marked by Paleozoic rocks exposed at the surface in a narrow band (Wells 1933, Miller 1974). It extends beyond Crowley's Ridge in Arkansas to the west, to the vicinity of the Tennessee River to the east, and down through all of Mississippi and Louisiana to the south (Wells 1933, Miller 1974, Luther 1977). Wells (1933) described the Mississippi Embayment as "...a down-warped trough of Paleozoic rocks pitching gently to the south, whose upper end is in southern Illinois and whose axis roughly parallels the Mississippi River but lies a few mile west of it."

The Pleistocene ice age had a great influence on the development of the modern floodplains of the Mississippi Embayment. When the massive ice sheet covered the northern half of the continent, the sea level was more than 100 m lower than it is today. This enormous mass of ice tilted the northern part of the continent downward and the southern part upward (Luther 1977). The streams of the Mississippi Embayment responded by cutting deep gorges through the sediments deposited earlier (Luther 1977). The glaciers retreated at the end of the Pleistocene 10,000 years ago, releasing vast quantities of water which moved large amounts of glacial debris (Wells 1933). The subsequent rise of the sea and tectonic rebound of the continent caused the streams to fill their gorges with alluvium (Luther 1977, Wharton et al. 1982).

The Coastal Plain streams of the present, including those in western Tennessee, also are "underfit" for their valleys (i.e., their discharges are too small to have produced the valley morphology that currently exists) (Wharton et al. 1982). The discharge of rivers was much greater 12,000 years ago than at present, possibly by as much as 18-fold (Wharton et al. 1982). Discharge rates began to subside about 10,000 years ago, and the streams adjusted by abandoning parts of their floodplains and lowering their base level, thus producing terraces (Wharton et al. 1982). These relict floodplain surfaces have not yet been completely eroded by lateral migration of the rivers and remain higher than the active floodplain (Wharton et al. 1982, Saucier 1987). The most significant cause of terrace formation in the lower reaches of western Tennessee streams, however, was the glacial outwash deposited in the Mississippi River valley; it controlled base levels of Mississippi Embayment streams (Saucier 1987).

The most recent geologic process of significance in western Tennessee was the deposition of a layer of silty material (loess) over much of the region. This was the result of Pleistocene glacial deposits drying and being transported from the Mississippi Alluvial Valley by easterly winds (Wells 1933, Luther 1977).

Soils

Springer and Elder (1980) described the soils within the river bottoms of reference domain. Most soils are deep, friable, and silty in texture. They range from medium to strongly acid in the eastern portion of the ecoregion to nearly neutral farther west where the loess is thicker. Subsoils usually contain moderate amounts of phosphorus and low amounts of potassium. Most are "somewhat poorly drained," although they vary from "well drained" to "very poorly drained." Most are in the Order Entisol and Great Groups Fluvaquents and Udifluvents. Three major soil series found in the river bottoms, Waverly, Falaya, and Collins, make up 80 percent of the total. These three soils are similar, differing mainly in drainage. Other minor soils found in the bottomlands of the Loess Plain ecoregion are listed in Table 6. Most are designated as "hydric soils" by the Hydric Soil Technical Committee (USDA Natural Resources Conservation Service (NRCS) 1995), although two (Morganfield and Vicksburg) are not.

Table 6
Soils Found in Floodplains of the Western Tennessee Reference Domain

Series Name	Drainage Class	Hydric Designation
Morganfield	Well	No
Ochlockonee	Well	No
Vicksburg	Well	No
Adler	Moderately well	No
Collins	Moderately well	No
Oaklimeter	Moderately well	Yes
Arkabutla	Somewhat poorly	Some phases hydric
Convent	Somewhat poorly	Some phases hydric
Falaya	Somewhat poorly	Some phases hydric
Vacherie	Somewhat poorly	No
Wakeland	Somewhat poorly	No
Birds	Poorly	Yes
Rosebloom	Poorly	Yes
Tichnor	Poorly	Yes
Waverly	Poorly	Yes
Dekoven	Very poorly	Yes

The parent material for these bottomland soils primarily has been loess-rich sediments washed in over the last 200 years from the upland areas, thus the soils have a high proportion of silt (Springer and Elder 1980). The area is underlain

with sandy or clayey coastal plain sediments (Talley and Monteith 1994). The soils are highly productive for plant growth, but are highly erodible when cleared (Talley and Monteith 1994).

Climate

The Coastal Plain of Tennessee has a temperate, humid climate. Local climatic conditions are a result of warm, moist maritime air masses from the Gulf of Mexico mixing with cold, dry continental air masses. This produces a great deal of seasonal variability in precipitation. The mean annual precipitation is 110 cm, with the wettest periods in late winter and early spring and the driest periods in September and October (USDA-NRCS 1995). Winter precipitation results largely from frontal storm systems, and summer precipitation comes from convective storm activity.

Average daily temperatures range from 3.5 °C in January to 30 °C in July, and 215 to 250 days per year have a daily minimum temperature greater than -2 °C (USDA-NRCS 1995). Springer and Elder (1980) record the approximate date of the last freeze in spring to be March 31 and the first freeze in the fall to be October 25. These seasonal variations in precipitation, temperature, and evapotranspiration affect river discharge and other surface and subsurface sources that supply water to low gradient riverine wetlands.

Bottomland hardwood community

Bottomland hardwood forests (BLHs) in the reference domain have distinct and recognizable assemblages of plants associated with particular landforms, soils, and hydroperiods. The primary natural vegetation is oak-hickory and other species associated with floodplain forests, although most forest cover has been removed for conversion to agriculture (Griffith et al. 1997). A floristic study of BLHs in western Tennessee identified 16 forest community types based on overstory species dominance and the classification of floodplain zones (Patterson and DeSelm 1989) (Table 7). These 16 communities contain more than 46 species of canopy trees, approximately two-thirds of the 70 known to occur within BLHs. In spite of the large number of species that do occur, relatively few dominate BLHs in a particular area. For example, 12 species comprise 90 percent of the total population of trees in BLHs in the Mississippi Embayment (McKnight et al. 1981).

There is considerable similarity between the classification systems used by Patterson and DeSelm (1989) and Wharton et al. (1982), and the zones in which the respective authors place the communities often coincide closely. For example, both classifications place bald cypress -water tupelo dominated communities in Zone II and an overcup oak-water hickory dominance type within Zone III. Zone IV described by Wharton et al. (1982) is dominated primarily by diamondleaf oak (*Q. laurifolia*), which does not occur in western Tennessee, but associates such as green ash, American elm (*Ulmus americana*),

Table 7
Western Tennessee BLH Community Types by Zone[1]

Zone	Community
II	Bald cypress
	Water tupelo - bald cypress
	Water tupelo
III	Black willow
	Black willow - bald cypress
	Bald cypress - hardwood
	Water hickory - overcup oak
IV	Red maple - mixed bottomland hardwood
	Green ash
	Sweetgum - mixed bottomland hardwood
V	Sugarberry - mixed bottomland hardwood
	Shellbark hickory
	Cherrybark oak
	Willow oak
	Slippery elm - mixed bottomland hardwood
	Box elder

[1] Source: Patterson and DeSelm 1989.

and sweetgum do and also are listed by Patterson and DeSelm (1989). Zone V, the highest portions of the floodplain, are characterized by cherrybark oak and swamp chestnut oak in both classifications.

Wilder and Roberts (2002) studied mature BLHs associated with both altered and unaltered river systems in the reference domain. They collapsed the zones identified by Wharton et al. (1982) into three easily recognizable portions of the floodplain: depressions (concave areas), flats (no obvious relief), and ridges (convex areas). This also was the basis for segregating data sets for scaling models for each zone in this guidebook for western Tennessee. Three distinct data sets were collected, one for each zone (depression, flat, ridge). Dominant overstory species in depressions in both types (altered and unaltered) included baldcypress and water tupelo; few shrubs were present. Dominant overstory species in unaltered flats were green ash, sweetgum, slippery elm (*Ulmus rubra*), overcup oak, swamp chestnut oak, and willow oak. Ironwood (*Carpinus caroliniana*) was a common understory species. In channelized systems, oaks were less common in the overstory, and red maple, virtually absent in unaltered systems, made up a substantial portion of the canopy. Ridges in both altered and unaltered systems had sweetgum, swamp chestnut oak, willow oak, and

cherrybark oak as canopy dominants. Ironwood, pignut hickory (*Carya glabra*), and paw-paw (*Asimina triloba*) were common midstory and shrub species. Some minor differences existed between types in the makeup of the midstory layer.

Additional data collected by Dr. Scott Franklin (University of Memphis) at moderately and severely altered sites make up the reference data set used to scale the vegetation variables in the models presented in this guidebook.

Hydrologic regimes

The interaction of climate, basin/watershed, channel, and site-specific characteristics affect the magnitude, frequency, and duration of water moving through the basin which, in turn, affects where low-gradient riverine wetlands occur. Long-term temperature, precipitation regime, and other climatic factors influence the rate at which water is delivered and lost from a watershed. Basin characteristics such as shape, size, slope, geology, etc., affect how water and sediment move through the watershed. Watersheds in the reference domain generally are elongate in shape, greater than 2,500 km^2 (1,000 square miles) in size, have low slopes (0.01- 0.05 percent; 0.3-0.9 m (1-3 ft)/mile), moderate relief, and low drainage densities which contribute to slowly rising flood stages, broad hydrograph peaks, and slow recession.

Precipitation patterns strongly influence the magnitude and frequency of floods. Seasonally variable factors such as evapotranspiration, antecedent soil moisture, and the extent, duration, and intensity of storm systems all influence flood response. Typically, annual maximum discharge for rivers in the reference domain occurs most frequently in late winter and early spring. Presumably this is due to low potential evapotranspiration rates (PETs) which occur prior to spring leaf-out (i.e., the growing season), leading to saturated soil conditions which in turn result in greater surface runoff and subsurface discharge which culminate in flood conditions. In large drainage basins (129-2590 km^2 (50-1000 square miles)), the annual maximum peaks occurred between January and April due to low intensity, long duration, frontal storms. Conversely, high intensity, short duration, convective storms in the summer may cause flooding in smaller (<129 km^2 (<50 square miles)) basins.

The bottomlands in this regional subclass are saturated and/or inundated frequently (i.e., annually) and for durations long enough to develop and sustain wetland conditions (i.e., typically greater than 5 percent of the growing season, or approximately 12 days). Springer and Elder (1980) noted that most of the areas are flooded periodically, from 2 to 6 times every 10 years, and that, in some places, water stands for weeks. The saturated soil conditions, which contribute to flooding, also contribute to the maintenance of subsurface hydrology, biogeochemistry, and habitat functions in these low gradient riverine wetlands. Therefore, it is the combination of surface and subsurface hydrology that provides the water source and hydrodynamics for this wetland subclass.

Cultural alteration of rivers, floodplains, and the landscape

Western Tennessee was settled rapidly after the Jackson-Shelby Treaty of 1818 (Tennessee State Planning Office 1978), and changes to the landscape began immediately. The uplands were cleared of hardwood forests, but most bottoms were left in forest cover. The volume of timber that was produced helped make Memphis the world's leading hardwood processing center during the last half of the 19th Century (Barnhardt 1988). Cleared areas were planted in corn, cotton, and tobacco, and the produce was shipped by river. Towns such as Bolivar, Jackson, and Dyersburg developed as river ports. As early as 1825, actions were undertaken to improve the river transportation in western Tennessee (Tennessee State Planning Office 1978). In 1838, $93,000 was appropriated by the state legislature to improve navigation on the Hatchie, Forked Deer, and Obion Rivers. When the first steamboat arrived in Brownsville in 1828, the Forked Deer and Hatchie Rivers were 12 ft deep, 50 ft wide, and navigable through three-quarters of their length. During the 1830s, 100-ton steamships may have navigated as far upstream as Jackson (Tennessee State Planning Office 1978).

Erosion was accelerated in western Tennessee by deforestation and the farming practices of the 1800s (Barnhardt 1988). The loess and sandy soils of the area eroded rapidly once trees were removed, resulting in gullies over 15 m deep (Wells 1933, Barnhardt 1988). Areas were abandoned as erosion made them unfit for cultivation (Hidinger and Morgan 1912, Wells 1933). Wells (1933) compared these areas with the Badlands of the Dakotas. Prior to European settlement, the floodplains of western Tennessee had vertical accretion rates ranging from 0.02 to 0.09 cm a year (Wolfe and Diehl 1993). Wolfe and Diehl (1993) estimated post-settlement sedimentation rates up to 3 cm a year from their radiocarbon analysis of buried cypress stumps. They also made several observations of floodplain soil layers in areas of the North Fork of the Forked Deer River floodplain. They concluded that the poorly formed soils represented from 1.5 to 3.6 m of sediment deposition in the century prior to 1930 (Wolfe and Diehl 1993). Barnhardt (1988) found evidence of 1 m of deposition since the 1830s in gullies near Memphis.

By 1910, most of the upland areas (in the reference domain) were in cultivation or pasture (Morgan and McCrory 1910). It was believed that channelization and drainage would allow bottomlands to be farmed, thus the value of those lands would increase. A law authorizing the formation of drainage districts was enacted in 1910 (Ashley 1910a).

Early in the century, the channels of most western Tennessee streams were filled with sediment and debris (Ashley 1910b) and the State began investigating the feasibility and cost of flood control (Morgan and McCrory 1910, Hidinger and Morgan 1912). Methods investigated included channelization and the construction of "floodways" (Hidinger and Morgan 1912). Floodways consisted of a pair of parallel levees built on each side of the natural river channel far enough apart and of sufficient height to carry the river's floods. The

recommended method depended on the size of the watershed and the spacing and number of tributaries entering the valley.

In 1914, the first channelization project was begun on the South Fork of the Forked Deer River, and by 1920, over 132 km of stream had been channelized (Simon and Robbins 1987). By the mid 1920s, most of the streams in western Tennessee, with the exception of the Hatchie River, had been channelized to some extent. Channel work continued into the 1930s and 1940s on the Obion River and its forks (Robbins and Simon 1982). Work conducted between 1938 and 1952 on the Hatchie River channel was limited to clearing snags, thus its meandering course was preserved (Simon and Hupp 1992).

It is likely that the South Fork of the Forked Deer River was the first river to be channelized because it offered the most cost-effective options (Hidinger and Morgan 1912). It had a relatively wide valley for its drainage area and few tributaries to complicate construction of levees. The Hatchie, on the other hand, had numerous tributaries entering its valley at regular, relatively short intervals. It also had a large drainage area relative to its valley width, so "reclamation" was neither technically nor economically feasible (Hidinger and Morgan 1912).

Because of poor planning and coordination among the various drainage districts, by 1929, many of the drainage ditches bisecting the Obion-Forked Deer floodplains had not been maintained and no longer functioned (Tennessee State Planning Commission 1936, Barstow 1971). With passage of the Flood Control Act of 1948, the U.S. Army Corps of Engineers (USACE) began developing the West Tennessee Tributaries Project (WTTP) (Shankman and Samson 1991, Tennessee 1994). The USACE has coordinated most channelization projects in the area since then (Shankman and Samson 1991).

The WTTP called for the channelization of 360 km of stream in the Obion and Forked Deer River systems (Shankman and Samson 1991). The project began in 1961 in the lowest reaches of the watersheds (Shankman and Samson 1991, Tennessee 1994). Work proceeded upstream into the lower reaches of the Rutherford, South, Middle, and North Forks of the Obion and portions of the North and South Forks of the Forked Deer River (Simon and Hupp 1987, Simon and Robbins 1987, Tennessee State Planning Office 1994). A lawsuit for noncompliance with the National Environmental Policy Act (NEPA) resulted in a halt to the project by court order in 1970 (Shankman and Samson 1991, Tennessee 1994), at which time approximately 128 km (35 percent) of the planned channel work had been completed (Shankman and Samson 1991, Tennessee 1994).

The WTTP had a considerable impact on the Obion and Forked Deer River systems. Degradation progressed upstream of completed portions of the WTTP at rates of 1.6 to 2.6 km per year (Simon and Robbins 1987). Degradation dropped channel levels as much as 5 m, and mass wasting widened the channel by 1 to 4 m per year (Simon and Hupp 1987). Sediment aggradation in lower reaches of affected channels occurred at rates of 12 cm per year, with greater rates at stream mouths (Simon and Hupp 1987). Twelve years after

channelization, 2 m of sediment had been deposited in lower reaches of the South Fork of the Forked Deer River (Simon and Hupp 1992). Overall, affected streams were shortened 44 percent, lowered 170 percent, and steepened 600 percent (Simon and Hupp 1992).

Channelization and drainage projects have affected every river system in western Tennessee. In the Obion and Forked Deer River basins, virtually all of the rivers and most of the major tributaries have been channelized since 1920. The Wolf River has been channelized and dredged in the lower and upper parts of its watershed. Headcutting has progressed well above the channelized portion and, as of 1999, had reached the Shelby:Fayatte county line. Even the Hatchie River is not completely free of the effects of channelization, as many of its major tributaries have been channelized, including one of the biggest, the Tuscumbia River.

Tennessee has lost a substantial portion of its original BLHs as a result of the WTTP and associated drainage efforts (Governor's Interagency Wetlands Committee 1994). Bottomland hardwoods along completed sections of the WTTP were reduced 60 percent by 1971 and even oxbows and sloughs were lost (Barstow 1971). In areas the project had not yet reached, BLHs were cleared and ditches were constructed in anticipation of the drainage benefits (Barstow 1971). Between 1940 and 1971, 404,000 ha of BLHs were reduced to 291,000 ha in western Tennessee (Turner, Forsythe, and Craig 1981).

Description of reference standard sites

One reference standard site, the Hatchie National Wildlife Refuge (NWR) (HR), is located in Haywood County about 6 km south of Brownsville where I-40 crosses the Hatchie River. Part of the refuge extends downstream of I-40, but the majority of the refuge, including the area that was sampled, lies upstream. Approximately 3,400 ha of BLHs are included in the upstream unit of the Hatchie NWR; however, the valley of the Hatchie is almost completely forested from the Mississippi River upstream to the Tennessee/Mississippi state line, making HR part of a large forested corridor. With the exception of two short sections of river (each less than 1,000 m), the main stem of the Hatchie River has not been channelized in Tennessee. The watershed above the refuge is approximately 5,440 km^2.

The other reference standard area is within the Wolf River Wildlife Management Area (WMA) located 1 km south of LaGrange in Fayette County. About 1,200 ha comprise the WMA and it, too, is part of a larger forested corridor. Plots were located upstream and downstream of Yager Drive. The Wolf River has been channelized in its upper reaches in Mississippi and in its downstream reaches in Memphis. The river in the study area has not been channelized. There are 540 km^2 in the watershed above the WMA.

4 Wetland Functions and Assessment Models

The following functions performed by low gradient, riverine wetlands in western Tennessee were selected for assessment.

a. Function 1: Temporarily Store Surface Water

b. Function 2: Maintain Characteristic Subsurface Hydrology

c. Function 3: Cycle Nutrients

d. Function 4: Remove and Sequester Elements and Compounds

e. Function 5: Retain Particulates

f. Function 6: Export Organic Carbon

g. Function 7: Maintain Characteristic Plant Community

h. Function 8: Provide Habitat for Wildlife

The following sequence is used to present and discuss each of these functions:

Definition: defines the function and identifies an independent quantitative measure that can be used to validate the functional index.

Rationale for selecting the function: provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.

Characteristics and processes that influence the function: describes the characteristics and processes of the wetland and the surrounding landscape that influence the function and lay the groundwork for the description of model variables.

Description of model variables: defines and discusses model variables and describes how each model variable is measured for the flats zone. Appendix B contains graphs for transforming field measurements to indices for all zones.

Functional capacity index: describes the assessment model from which the functional capacity index is derived and discusses how model variables interact to influence functional capacity.

Function 1: Temporarily Store Surface Water

Definition

Temporarily Store Surface Water is defined as the capacity of a riverine wetland to temporarily store and convey floodwaters that inundate riverine wetlands during overbank flood events. Most of the water that is stored and conveyed originates from an adjacent stream channel. However, other potential sources of water include: (a) precipitation, (b) surface water from adjacent uplands transported to the wetland via surface channels or overland flow, and (c) subsurface water from adjacent uplands transported to the wetland as interflow or shallow groundwater and discharging at the edge or interior of the floodplain. A potential independent, quantitative measure for validating the functional index is the volume of water stored per unit area per unit time (m^3/ha/time) at a discharge that is equivalent to the average annual peak event.

Rationale for selecting the function

The capacity of riverine wetlands to temporarily store and convey floodwater has been extensively documented (Dewey and Kropper Engineers 1964; Campbell and Johnson 1975; Dybvig and Hart 1977; Novitski 1978; Thomas and Hanson 1981; Ogawa and Male 1983, 1986; Demissie and Kahn 1993). Many benefits related to the reduction of flood damage occur as a result of wetlands performing the function. For example, wetlands can reduce the velocity of the flood wave and, as a result, reduce peak discharge downstream. Similarly, wetlands can reduce the velocity of water currents and, as a result, reduce damage from erosion forces (Ritter, Kochel, and Miller 1995).

In addition to these direct benefits, there are a number of ecological processes that occur in riverine wetlands that depend on the periodic inundation that results from overbank floods. For example, as the velocity of the overbank flow is reduced, inorganic sediments and particulate organic matter settle out of the water column (Nicholas and Walling 1996; Walling, Quine, and He 1992; James 1985; Ritter, Kinsey, and Kauffman 1973). This provides a nutrient subsidy to plant communities on the floodplain and can contribute to an improvement in the quality of water in streams and rivers (Mitsch, Dorge, and Wiemhoff 1979). As floodwater inundates riverine wetlands, it also provides access to floodplain feeding and reproductive areas for fish and other aquatic organisms (Cobb 1997;

Kilgore and Baker 1996; Cobb 1989; Fremling et al. 1989; Junk, Bayley, and Sparks 1989; Scott and Nielson 1989; Ross and Baker 1983; Guillory 1979; Welcomme 1979; Gunderson 1968) and serves as a transport mechanism for plant propagules which may be important to the dispersal and regeneration of certain plant species (Johansson, Nilsson, and Nilsson 1996; Nilsson, Gardfjell, and Grelsson 1991; Schneider and Sharitz 1988). Finally, overbank floodwater facilitates the export of particulate and dissolved organic carbon from the riverine wetland to downstream aquatic food webs (Anderson and Sedell 1979, Mulholland and Kuenzler 1979).

Characteristics and processes that influence the function

The characteristics and processes that influence the capacity of a wetland to temporarily store floodwater are related to climate, watershed characteristics, and conditions in the stream channel adjacent to the wetland, as well as conditions in the wetland itself. In general, the intensity, duration, and areal extent of precipitation events affect the magnitude of the stormflow response. Typically, the higher the intensity, the longer the duration, and the greater the areal extent of a particular rainfall event, the greater the flood peak. Watershed characteristics such as size and shape, channel and watershed slopes, drainage density, and the presence of wetlands and lakes have a pronounced effect on the stormflow response (Brooks et al. 1991; Dunne and Leopold 1978; Ritter, Kochel, and Miller 1995; Leopold 1994; Patton 1988). The larger the watershed, the greater the volume and peak of streamflow for rainfall events. Watershed shape affects how quickly surface and subsurface flows reach the outlet to the watershed. For example, a round-shaped watershed concentrates runoff more quickly than an elongated one and will tend to have higher peak flows. Steeper hillslopes and channel gradients also result in quicker response and higher peak flows. The higher the drainage density (i.e., the sum of all the channel lengths divided by the watershed area), the faster water is concentrated at the watershed outlet and the higher the peak. As the percentage of wetland area and/or reservoirs increases, the greater the flattening effect (attenuation of) on the stormflow hydrograph. In general, these climatic and watershed characteristics are the same in a given region and are considered constant for the purposes of rapid assessment. However, site-specific characteristics of riverine wetlands can vary and are the emphasis of this function.

Depth, frequency, and duration of flooding in the wetland are the manifestation of the watershed stormflow response and the characteristics mentioned above. Conditions conducive to flooding are dictated, to a large degree, by the nature of the stream channel and its floodplain. The morphology of the stream channel and its floodplain reflect the discharges and sediment loads that have occurred in the past. Under stable flow and sediment conditions, the stream and its floodplain will eventually achieve equilibrium. Alteration to the stream channel or its watershed may cause instability that results in channel aggradation or degradation and a change in depth, frequency, and duration of overbank flow events (Dunne and Leopold 1978; Rosgen 1994). As the stream channel aggrades, available water storage in the channel decreases, resulting in

greater depth, frequency, and duration of flooding and an increase in the amount of surface water stored in the wetland over an annual cycle. Conversely, as the stream channel degrades, available water storage in the channel increases, resulting in less depth, frequency, and duration of flooding and a decrease in the amount of surface water stored in the wetland over an annual cycle. The duration of water storage is secondarily influenced by the slope and roughness of the floodplain. Slope refers to the gradient of the floodplain across which floodwaters flow. Roughness refers to the resistance to flow created by vegetation, debris, and topographic relief. In general, duration increases as roughness increases and slope decreases.

Description of model variables

Overbank Flood Frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency at the scale of the riverine wetland reflects upstream watershed and channel conditions. In the context of this function, overbank flood frequency indicates how often peak seasonal discharges inundate a riverine wetland and allow surface water to be temporarily stored.

A fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999) is used to quantify this variable (this and other methods to quantify this variable are described in Appendix C). Overbank flood frequency is a function of discharge and channel capacity (cross-sectional area) and can be measured using the following procedure.

(1) Determine cross-sectional area of the channel adjacent to the wetland assessment area.

(2) Report the factor of departure of the measured channel cross-sectional area adjacent to the wetland assessment area from the expected channel cross-sectional area obtained from the regional curve or regression equation.

In western Tennessee reference standard wetlands, channel cross-sectional area is described by the regression equation $16.4 \times DA^{0.57}$. Based on the fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999), sites adjacent to rivers with areas within a factor of 2 are assigned a subindex of 1.0 (Figure 3). Sites adjacent to channels with a departure from the curve by a factor of 2 to 4 are assigned a subindex of 0.5. Sites with a

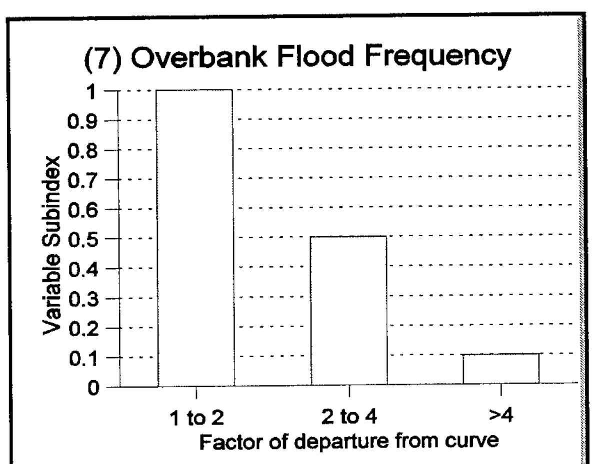

Figure 3. Function 1: Relationship between channel cross-sectional area and functional capacity

departure of greater than 4 are assigned a subindex of 0.1. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the cross-sectional area of the channel, a greater discharge is required to overtop the bank and innundate the riverine wetland. Since greater discharges occur with less frequency, the volume of water temporarily stored in riverine wetlands is less than that characteristically stored at reference standard sites. The rationale at which the subindex is scaled is based on data from the USGS gage at Bolivar for the growing season over a 67-year period, and the magnitude of scatter within the data used to develop the regional curve (Appendix C). Model validation will help refine the actual nature of this relationship.

Floodplain Storage Volume (V_{STORE}). This variable represents the volume that is available for storing surface water during overbank flood events. In western Tennessee, the loss of storage volume is usually a result of levees, roads, or other man-made structures that reduce the effective width of the floodplain at least below the design discharge. In the context of this function, this variable is designed to detect changes in storage volume that result from these types of structures.

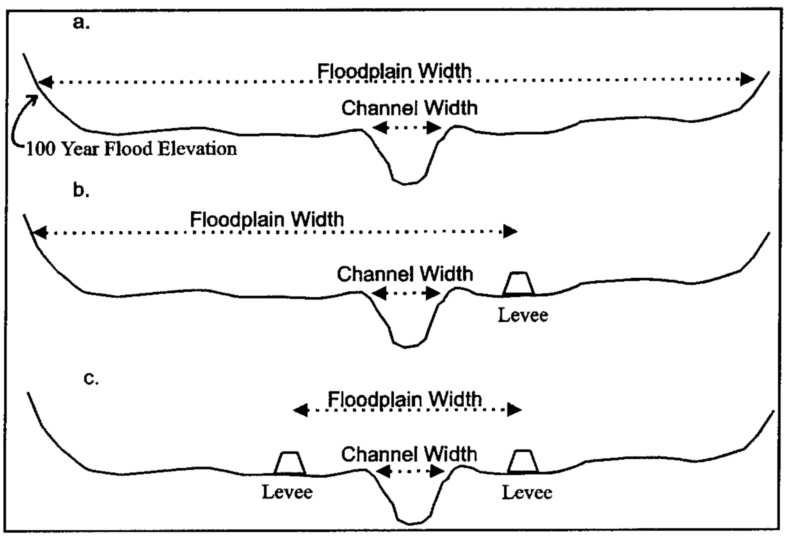

Figure 4. Determining floodplain width and channel width

The ratio of floodplain width to channel width is used to quantify this variable. Floodplain width is defined as the distance between the 100-year flood elevation contour lines on opposite sides of the stream measured perpendicular to the channel (Figure 4a). Where artificial levees, or roads that function as levees, occur, floodplain width is the distance between the riverside toe of the levee or road and the 100-year flood elevation contour (Figure 4b) or the riverside toe of a levee or road on the opposite side of the stream (Figure 4c). Channel width is defined as the distance between the top of the channel banks measured perpendicular to the channel. As the ratio decreases, floodplain storage volume decreases.

Measure the ratio of floodplain width to channel width with the following procedure.

(1) Measure the width of the floodplain and the width of the channel using surveying equipment or by pacing in the field. A crude estimate can be made using topographic maps or aerial photos, remembering that short distances on maps and photographs translate into long distances on the ground (i.e., the width of a section line on a 1:24,000 USGS topographic map represents about 9.1 m (30 ft) on the ground).

(2) Calculate the ratio by dividing the floodplain width by the channel width.

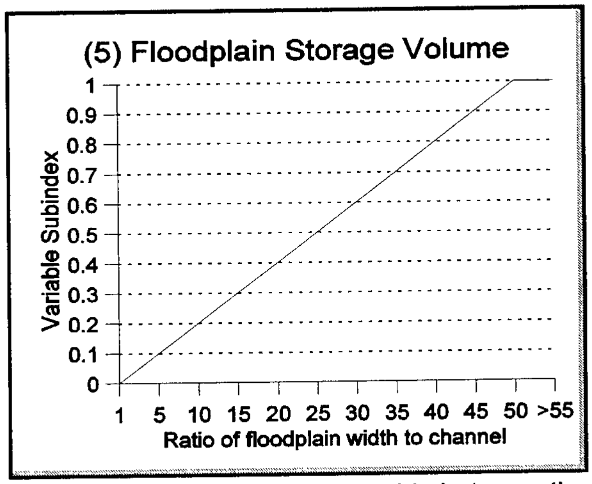

Figure 5. Function 1: Relationship between the ratio of floodplain width to channel width and functional capacity

(3) Report the ratio of floodplain width to channel width as a unitless number.

In western Tennessee reference wetlands, the ratio of floodplain width to channel width ranged from 35 to 175 (Appendix D). Based on the range of values at reference standard wetlands, a variable subindex of 1.0 is assigned to ratios ≥53 (Figure 5). Smaller ratios are assigned a linearly decreasing subindex down to 0 at a ratio of 1. This is based on the assumption that the ratio of floodplain width to channel width is linearly related to the capacity of riverine wetlands to temporarily store surface water.

Floodplain Slope (V_{SLOPE}). This variable represents the longitudinal slope of the floodplain in the vicinity of the riverine wetland. The relationship between slope and the temporary storage of surface water is based on the proportional relationship between slope and velocity in Manning's equation:

$$V = \frac{1.49 \times R^{2/3} \times S^{1/2}}{n} \quad (1)$$

where

V = mean velocity of flow (ft/s)

R = hydraulic radius (ft)

S = slope (ft/ft)

n = roughness coefficient

Generally, the flatter the slope, the slower the water moves through the riverine wetland. In the context of this function, the variable is only likely to change significantly when the slope of the floodplain has been altered by surface mining, the placement of structures in the channel, or other slope altering activities.

Percent floodplain slope is used to quantify this variable. Measure it with the following procedure.

(1) Determine the change in elevation between two points along the floodplain center line (i.e., center line of the meander belt of the active channel) on a river reach representative of the area being assessed (Figure 6). This can be accomplished using the contour lines on a standard 7.5 minute USGS topographic map. The distance between the two points should be great enough so that local anomalies in floodplain slope do not influence the result. As a rule of thumb, the line between the two points should intersect at least two contour lines on a 1:24,000 scale (7.5 minute) USGS topographic map (Figure 6).

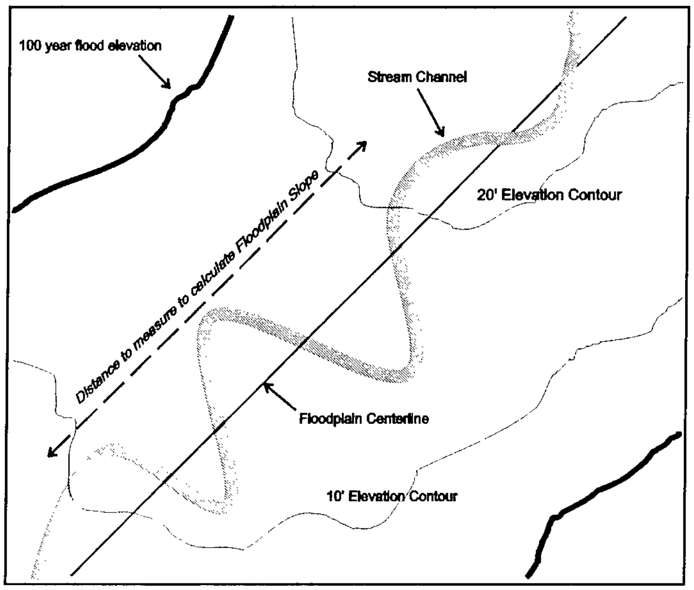

Figure 6. Measuring floodplain slope

(2) Determine the straight line distance between the two points.

(3) Divide the change in elevation by the distance between the two points. For example, if the change in elevation between the two points is 3.0 m (10 ft) and the distance between the two points is 1.6 km (1 mile), the slope is 3.0 m /1,000 m = 0.002.

(4) Convert the slope to a percent slope by multiplying by 100.

(5) Report floodplain slope as a percent.

In western Tennessee reference wetlands, floodplain slopes ranged from 0.01-0.09 percent (Appendix D). Reference standard wetland sites had floodplain slopes of 0.04 percent. A variable subindex of 1.0 is assigned to floodplain

slopes ≤0.09 percent (Figure 7). In the western Tennessee reference domain, no large scale floodplain alterations have occured, thus this variable normally will have a subindex value of 1.0.

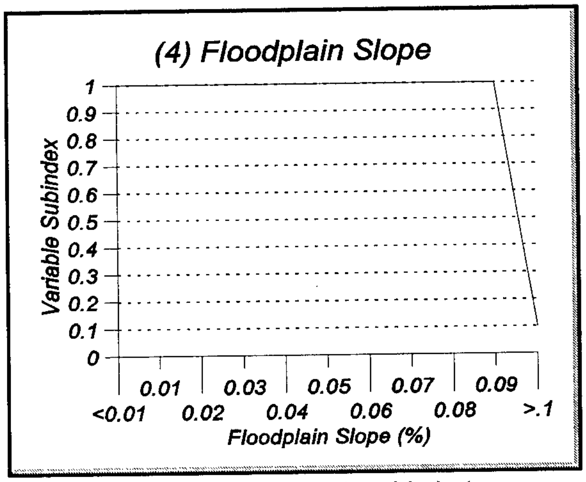

Figure 7. Function 1: Relationship between floodplain slope and functional capacity

Floodplain Roughness (V_{ROUGH}). This variable represents the resistance to the flow of surface water resulting from physical structures on the floodplain. The relationship between roughness and the velocity of surface water flow is expressed by Manning's equation which indicates that as roughness increases, velocity decreases and storage time increases (Equation 1). Several factors contribute to roughness, including the soil surface, surface irregularities (e.g., micro- and macrotopographic relief), obstructions to flow (e.g., stumps and coarse woody debris), and resistance due to vegetation structure (trees, saplings, shrubs, and herbs). Depth of flow is also an important consideration in determining roughness because as water depth increases, obstructions are overtopped and cease to be a source of friction or turbulence, causing the roughness coefficient to decrease.

Manning's roughness coefficient (n) is used to quantify this variable. Measure n at the depth of flooding indicated by onsite data (e.g., stage recorder) or by hydrologic indicators (i.e., silt lines, water marks, bryophyte - lichen lines, debris lines, etc.). If onsite data or indicators are not present, evaluate n at or slightly above ground surface (i.e., within 0.3 m (1 ft)). Once the depth of flooding is determined, measure n using one of the following procedures.

(1) Alternative 1: Use Arcement and Schneider's (1989) method for estimating Manning's roughness coefficient, based on a characterization of the different components that contribute to roughness on floodplains which include micro- and macrotopographic relief (n_{TOPO}), obstruction (n_{OBS}), and vegetation (n_{VEG}). The following steps are needed to use this method:

(a) Determine n_{BASE}, the contribution to roughness of the soil surface. Arcement and Schneider (1989) suggest using 0.03, the value for firm soil.

(b) Using the descriptions in Table 8, assign adjustment values to the roughness components of n_{TOPO}, n_{OBS}, and n_{VEG}.

(c) Sum the values of the roughness components to determine floodplain roughness. For example, Manning's roughness coefficient $(n) = n_{BASE} + n_{TOPO} + n_{OBS} + n_{VEG}$.

Table 8
Adjustment Values for Roughness Components Contributing to Manning's Roughness Coefficient (*n*)

Roughness Component	Adjustment to *n* value	Description of Conditions
Topographic relief (n_{TOPO})	0.0	Representative area is flat with essentially no microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales).
	0.005	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) cover 5-25% of a representative area.
	0.01	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) cover 26-50% of a representative area.
	0.02	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) cover >50% of a representative area.
Obstructions (n_{OBS}) (includes coarse woody debris, stumps, debris deposits, exposed roots)	0.0	No obstructions present
	0.002	Obstructions occupy 1-5% of a representative cross sectional area .
	0.01	Obstructions occupy 6-15% of a representative cross sectional area.
	0.025	Obstructions occupy 16-50% of a representative cross sectional area.
	0.05	Obstructions occupy >50% of a representative cross sectional area.
Vegetation (n_{VEG})	0.0	No vegetation present
	0.005	Representative area covered with herbaceous or woody vegetation where depth of flow exceeds height of vegetation by > 3 times.
	0.015	Representative area covered with herbaceous or woody vegetation where depth of flow exceeds height of vegetation by > 2-3 times.
	0.05	Representative area covered with herbaceous or woody vegetation where depth of flow is at height of vegetation.
	0.1	Representative area fully stocked with trees and with sparse herbaceous or woody understory vegetation.
	0.15	Representative area partially to fully stocked with trees and with dense herbaceous or woody understory vegetation.

Note: After Arcement and Schneider (1989) and Aldridge and Garrett (1973)

(2) Alternative 2 (not recommended): Compare the area to be assessed to the photographs of forested floodplains presented in Arcement and Schneider (1989). These photographs illustrate a variety of conditions for which Manning's roughness coefficient has been calculated empirically and can be used in the field to estimate Manning's roughness coefficient for sites that are well stocked with trees.

(3) Report Manning's roughness coefficient as a unitless number.

In the flat zone of western Tennessee reference wetlands, Manning's roughness coefficients ranged from 0.035 to 0.24 (Appendix D). These values

were based on setting n_{BASE} to 0.03 and adjustment values for the topographic relief component (n_{TOPO}) that ranged from 0.005-0.01, the obstructions component (n_{OBS}) that ranged from 0.01-0.05, and the vegetation component (n_{VEG}) that ranged from 0.05-0.15.

Based on the range of values at reference standard sites, a variable subindex of 1.0 is assigned to Manning's roughness coefficients between 0.055 and 0.19 (Figure 8). Sites with higher roughness coefficients are also assigned a subindex of 1.0, based on the assumption that the increased roughness does not significantly increase retention time. Lower roughness coefficients were assigned a linearly decreasing subindex down to 0.5 at ≤0.03.

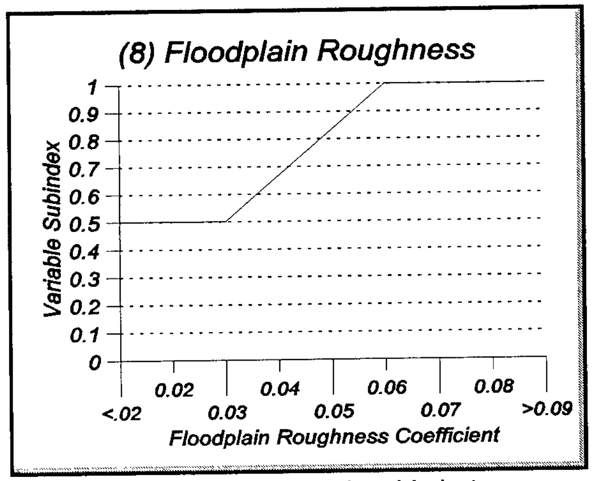

Figure 8. Function 1: Relationship between floodplain roughness and functional capacity

Functional capacity index

The assessment model for calculating the functional capacity index (FCI) is as follows:

$$FCI = \left[\left(V_{FREQ} \times V_{STORE} \right)^{1/2} \times \left(\frac{F_{SLOPE} + V_{ROUGH}}{2} \right) \right]^{1/2} \qquad (2)$$

In the model, the capacity of a riverine wetland to temporarily store surface water depends on three characteristics. In the first part of the model, V_{FREQ} indicates the ability of water to get to the riverine wetland as reflected by recurrence interval. The variable V_{STORE} indicates the volume that is available for storing surface water and reflects whether this volume has been reduced by structures (i.e., levees), fill, or other cultural alterations. The relationship between V_{FREQ} and V_{STORE} is assumed to be partially compensatory. This means that the variables contribute independently and equally to the performance of the function (WRP in preparation, Chapter 4). A geometric mean is used to average the two values. The use of a geometric means that if the subindex of a variable drops to zero, the results from that particular portion of the model will be zero. For example, if the subindex for V_{STORE} drops to zero, the results from the first half of the model will be zero. In this particular model, the FCI will also drop to zero because a geometric mean is used to combine the first and second half of the model. This simply means that as the recurrence interval decreases, or as the width of the floodplain is increasingly constricted by levees or roads, temporary surface water storage is reduced or, in the case of a variable subindex dropping to zero, eliminated. Use of an arithmetic mean to combine V_{FREQ} and V_{STORE} or the first and second part of the equation would require that the subindices for all

variables be zero in order for the FCI to equal zero, which is clearly inappropriate in this model.

In the second part of the model, V_{ROUGH} and V_{SLOPE} reflect the ability of the wetland to reduce the velocity of water as it moves through the wetland. These variables are also assumed to be partially compensatory, but in this case they are combined using an arithmetic mean. This makes the model relatively less sensitive to low subindices of V_{ROUGH} and V_{SLOPE} (WRP in preparation, Chapter 4). This is consistent with the assumption that V_{ROUGH} and V_{SLOPE} are less important in determining functional capacity than either V_{FREQ} or V_{STORE}.

Function 2: Maintain Characteristic Subsurface Hydrology

Definition

Maintain Characteristic Subsurface Hydrology is defined as the capacity of a riverine wetland to store and convey subsurface water. Potential sources of subsurface water are direct precipitation, interflow (i.e., unsaturated subsurface flow), groundwater (i.e., saturated subsurface flow), and overbank flooding. A potential independent, quantitative measure for validating the functional index is the cumulative number of days in a year that a characteristic depth to water table is maintained.

Rationale for selecting the function

Maintaining a characteristic subsurface hydrology in riverine wetlands is important for at least three reasons. First, it ensures that the biogeochemical processes and plant and animal communities that depend on subsurface water continue to exist. It also ensures that subsurface contributions to the baseflow and stormflow components of the stream hydrograph, originating in variable source areas (Kirkby 1978, Freeze and Cherry 1979), are maintained. The stream hydrograph has a strong influence on the development and maintenance of habitat structure and biotic diversity of adjacent stream ecosystems (Bovee 1982, Estes and Orsborn 1986, Stanford et al. 1996). Finally, the seasonal fluctuation of the water table that occurs in some riverine wetlands makes soil pore space for below-ground storage available during flood events.

Characteristics and processes that influence the function

Because of their unique transitional location, riverine wetlands influence subsurface water as it moves down the hydraulic gradient from upland areas to the stream channel (Figure 9). As water infiltrates and percolates through upland soils, it follows one of several pathways. For example, it may be lost through

evapotranspiration or to a deep regional groundwater path (Winter 1976, 1978). Alternatively, subsurface water can move down toward the riverine wetland in an unsaturated zone as interflow or in a saturated zone as shallow groundwater (Roulet 1990, O'Brian 1980, Kirkby 1978,). When subsurface water moving as interflow or shallow groundwater reaches the floodplain, it typically encounters a lower slope and substrates with lower hydraulic conductivity and higher porosity (i.e., silty clay and clay soils). These factors combine to reduce the velocity at which subsurface water moves through the riverine wetland to the stream channel. This contributes to the relatively high water table and/or saturated soil conditions often found in riverine wetlands and the ability of riverine wetlands to maintain discharges to the stream channel for long periods.

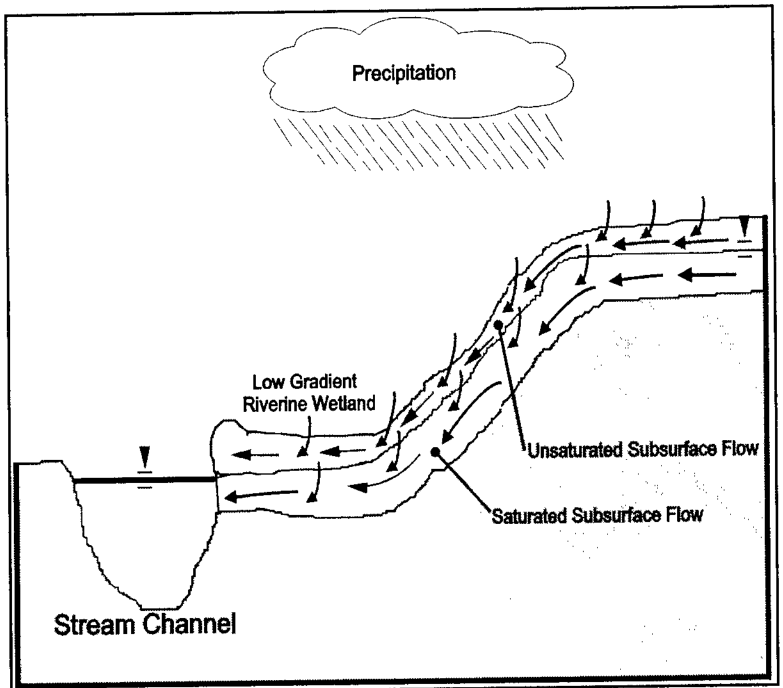

Figure 9. Movement of water down the hydraulic gradient from uplands, through wetlands, and into adjacent stream channels

Assessing the movement of subsurface water through riverine wetlands requires consideration of the factors that influence the movement of water through porous material. These factors are described in Darcy's general equation (Fetter 1988):

$$Q = -K_{SAT}\, A\left(\frac{dh}{dl}\right) \tag{3}$$

where

Q = discharge (volume/time)

K_{SAT} = saturated hydraulic conductivity for the material being observed (distance/time)

A = area through which water is flowing (length^2)

dh/dl = hydraulic gradient or change of head over length of water flow (length/length)

Saturated hydraulic conductivity is determined by the characteristics of the soil and the nature of the fluid moving through the soil (Fetter 1988, Heath 1987). However, since the only fluid of interest here is water, properties of the fluid, such as specific weight and dynamic viscosity, can be considered constant. This leaves the characteristics of the soil as the only factors of concern in determining saturated hydraulic conductivity (Watson and Burnett 1993). Modern county soil surveys provide information on the permeability of soils, which is equivalent to saturated hydraulic conductivity (USDA NRCS 1996).

The area factor (A) in Darcy's general equation, like the properties of the fluid, can be considered constant for the purposes of rapidly assessing subsurface hydrology. The final factor in Darcy's general equation, hydraulic gradient, can be thought of as the force that moves water through the soil. Increasing the hydraulic gradient will increase discharge in the same type of soil. However, soils with different hydraulic conductivities that are subjected to the same hydraulic gradient will transmit water at different rates. For example, water will move through a sandy soil faster than through a clay soil under the same hydraulic gradient because the sandy soil has a higher hydraulic conductivity. In the context of rapid assessment, the slope of the water table from uplands to the stream channel represents the hydraulic gradient in Darcy's general equation.

There are a variety of activities that have the potential to alter subsurface hydrology in riverine wetlands. For example, agricultural activity, silvicultural activity, placement of fill, or the compaction of soil with heavy equipment during construction projects or surface mining can alter soil permeability and porosity. Other alterations, such as construction of ditches, installation of drainage tile, and channelization, can change the slope of the water table and, hence, the hydraulic gradient in riverine wetlands.

Description of model variables

Subsurface water velocity ($V_{SOILPERM}$). This variable represents the rate at which subsurface water moves down the hydraulic gradient through riverine wetland soils and into the stream channel. When the velocity of subsurface water is high, subsurface water moves through the riverine wetland relatively quickly, and the period of time that subsurface water discharges to the adjacent stream is short. When velocity is slow, subsurface water moves through more slowly, and the period of time that subsurface water discharges to the adjacent stream is longer.

Soil permeability is used to quantify this variable. Measure it with the following procedure.

(1) Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in construction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

(2) If soils have been altered, select one of the two following alternatives, otherwise skip to Step 3.

(a) Assign a value to soil permeability based on a representative number of field measurements of soil permeability. The number of measurements will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(b) Assign a variable subindex based on the category of alteration that has occurred at the site (Table 9). (Note: in this particular situation, no value is assigned to soil permeability, rather a variable subindex is assigned directly.)

Table 9
Soil Permeability Values (in./hr) for Silvicultural, Agricultural, and Other Alterations

Alteration Category	"Typical" Soil Permeability After Alteration	Average Depth of Alteration Effects	Variable Subindex
Silviculture: normal activities compact surface layers and reduce permeability to a depth of about 15.2 cm (6 in.) (Aust 1994)	highly variable and spatially heterogeneous	top 15.2 cm (6 in.) of soil profile	0.7
Agricultural tillage: some surface compaction occurs as well as generally decreasing the average size of pore spaces which decreases the ability of water to move through the soil to a depth of about 15.2 cm (6 in.) (Drees et al. 1994).	highly variable and spatially heterogeneous	top 15.2 cm (6 in.) of soil profile	0.7
Construction activities/surface mining: compaction resulting from large equipment over the soil surface, cover of soil surface with pavement or fill material, or excavation and subsequent replacement of heterogeneous materials	highly variable and spatially heterogeneous	entire soil profile	0.1

(3) If the soils have not been altered, select one of the two following alternatives.

(a) Alternative 1: Assign a value to soil permeability based on a representative number of field measures of soil permeability. The number of field measures will depend on how variable and spatially heterogeneous the onsite soils are. Appendix C provides a procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(b) Alternative 2: Assign a value to soil permeability by calculating the weighted average of median soil permeability to a depth of

50.8 cm (20 in.). Information for the soil series that occur in western Tennessee riverine wetlands is in Table 10. Calculate the weighted average of median soil permeability by averaging the median soil permeability values to a depth of 50.8 cm (20 in.). For example, in Table 10 the Tichnor series has a median soil permeability value from a depth of 0-15.2 cm (0-6 in.) of 3.3 and a median soil permeability value from a depth of 15.3-50.8 cm (6.1-20 in.) of 2.8. Thus, the weighted average of the median soil permeability for the top 50.8 cm (20 in.) is $(6 \times 3.3) + (14 \times 2.8)) / 20 = 2.9$ (1.1) These weighted averages have been calculated and are found in Table 10 for several common western Tennessee soils.

Table 10
Soil Permeability at Different Depths for Soil Series in Western Tennessee

Soil Series	Depth, cm (in.)	Range of Soil Permeability, cm (in.) per hr	Weighted Average Soil Permeability in top 50.8 cm (20 in.), cm (in.) per hr
Adler	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Arkabutla	0-50.8 (0-20)	0.5-1.5 (0.2-0.6)	3.3 (1.3)
Collins	0-50.8 (0-20)	0.5-1.5 (0.2-0.6)	3.3 (1.3)
Convent	0-50.8 (0-20)	0.5-1.5 (0.2-0.6)	3.3 (1.3)
Falaya	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Oaklimeter	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Robinsonville	0-17.8 (0-7)/17.9-50.8 (7.1-20)	5.1-15.2 (2.0-6.0)/1.5-15.2 (0.6-6.0)	7.1 (2.8)
Rosebloom	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Tichnor	0-15.2 (0-6)/15.3-50.8 (6.1-20)	1.5-5.1 (0.6-2.0)/0.5-5.1 (0.2-2.0)	2.9 (1.1)
Waverly	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)

(4) Report soil permeability in inches/hour.

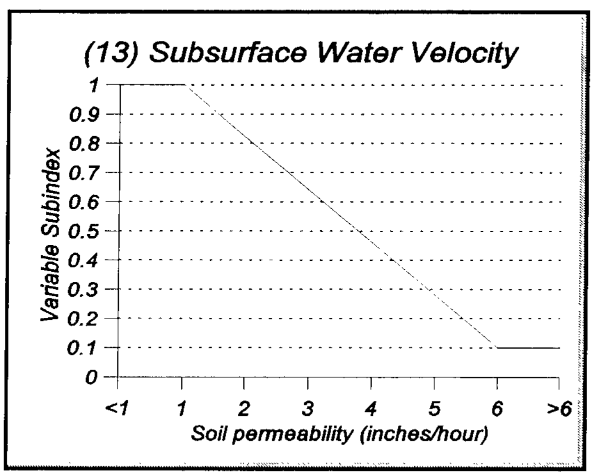

Figure 10. Function 2: Relationship between soil permeability and functional capacity

In western Tennessee reference wet lands, soil permeability ranged from 1.8 to 7.1 cm/hr (0.7 to 2.8 in./hr) (Appendix D) based on soil survey data. Based on the range of soil permeability at reference standard sites, a variable subindex of 1.0 was assigned to unaltered sites with a soil permeability <3.3 cm/hr (<1.3 in./hr) (rounded to 1.0 in Figure 10). As soil permeability increases, a decreasing subindex is assigned down to 0.1 at 15.2 cm/hr (6 in./hr) based on the assumption that the increase in soil permeability is linearly related to the capacity of a

riverine wetland to maintain characteristic subsurface hydrology. A soil permeability >6.0 is assigned a subindex of 0.1 based on the assumption that all soils, regardless of their permeability, reduce the velocity of water to some degree as it moves through the soil.

Sites altered by agricultural (e.g., plowing or cultivation) or silvicultural (e.g., cutting, shearing, or skidding) activities were assigned a variable subindex of 0.7 (Table 9). This is based on data from Aust (1994) and Drees et al. (1994) which indicate that, as a result of these activities, soil properties are generally altered in the top 15.2 cm (6 in.) of the soil profile. This means that soil permeability in the lower 35.6 cm (14 in.), or 70 percent of the 50.8 cm (20 in.) soil profile, is unaltered. Thus, a subindex of 0.7 is assigned. Sites altered by construction activities, surface mining, or other activities that affect the entire soil profile are assigned a subindex of 0.1 based on the fact that all soils, regardless of their permeability, reduce the velocity of water to some degree as it moves through the soil.

Water table slope ($V_{WTSLOPE}$). This variable represents the change in elevation of the water table moving from the upland areas adjacent to the riverine wetland to the nearest stream channel along a line perpendicular to the center line of the floodplain. It is assumed that, in unaltered riverine wetlands, the slope of the water table mimics the floodplain surface (Figure 11). The slope of the water table and, consequently, the velocity at which subsurface water moves down the hydraulic gradient can be modified by alterations such as ditching or tiling (Figure 11a). Channelization or dredging in the adjacent stream channel can also increase the water table slope and would be calculated in the same manner as above, with the channelized or dredged stream being treated in the same manner as a ditch (Figure 11b).

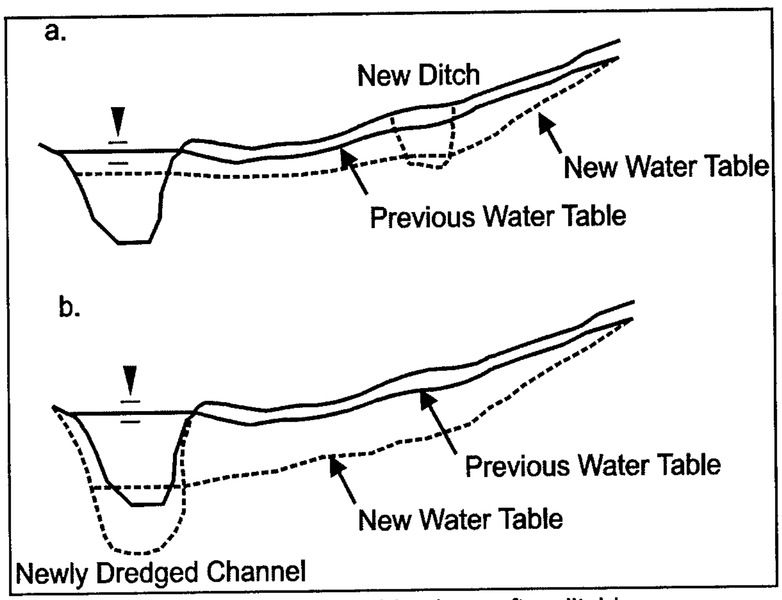

Figure 11. Change in water table slope after ditching or channel dredging

The percentage of the assessment area with an altered water table slope is used to quantify this variable. Measure it with the following procedure.

(1) Determine if the slope of the water table has been altered by ditching, tiling, dredging, channelization, or other activities with the potential to modify the water table slope.

(2) If the slope of the water table has not been altered, the percent of the area altered is 0.0.

(3) If the water table slope has been altered in any portion of the assessment area, determine the soil type and the "depth of the alteration." For example, if a ditch has been dug, the depth of the alteration is the depth of the ditch measured from the original ground surface. If a stream channel has been dredged, the depth of the alteration is the difference between the old and new channel depth.

(4) Use Table 11 to determine the lateral distance that will be affected by the alteration. The lateral distances listed in Table 11 are for one side of the ditch only. If the area being assessed extends to both sides of the ditch or channel alteration, then the lateral effect distances require doubling. For example, if the soil is in the Waverly series and the depth of the alteration is 1.5 m (5 ft), the lateral ditch effect is 234 m (769 ft). If the area being assessed extends on both sides of the ditch, the lateral effect is for 468 m (1,538 ft). The procedures used to calculate the values in Table 11 are based on the Ellipse Equation (USDA NRCS 1977) described in Appendix C.

Table 11
Lateral Effect of Ditches in Meters (ft) for Selected Soil Series in Western Tennessee

	Depth of Ditch or Change in Depth of Channel, cm									
Soil Series	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**150**	**200**	**250**
Adler	55 (181)	56 (184)	57 (186)	58 (188)	58 (189)	58 (191)	58 (192)	59 (193)	59 (194)	59 (194)
Arkabutla	69 (266)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	130 (426)	156 (512)	172 (566)	182 (597)
Collins	69 (226)	84 (275)	89 (291)	93 (306)	93 (307)	93 (307)	93 (307)	93 (307)	93 (307)	93 (307)
Convent	45 (147)	46 (152)	47 (156)	48 (157)	48 (157)	48 (159)	49 (160)	50 (166)	51 (169)	51 (169)
Dekoven	69 (226)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	124 (407)	127 (418)	132 (434)	133 (434)
Falaya	78 (256)	84 (275)	89 (291)	93 (306)	97 (320)	98 (321)	98 (322)	98 (323)	99 (324)	99 (324)
Oaklimeter	69 (226)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	124 (407)	124 (407)	124 (407)	124 (407)
Robinsonville	42 (139)	46 (152)	47 (156)	48 (159)	50 (163)	50 (164)	51 (168)	53 (174)	54 (177)	54 (177)
Rosebloom	69 (226)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	130 (426)	156 (511)	172 (566)	182 (597)
Tichnor	62 (204)	77 (252)	88 (289)	97 (320)	105 (346)	107 (352)	109 (358)	110 (361)	110 (361)	110 (361)
Vacherie	69 (226)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	124 (407)	127 (418)	132 (434)	133 (434)
Waverly	69 (226)	84 (275)	89 (291)	93 (306)	102 (336)	106 (348)	106 (348)	106 (348)	106 (348)	106 (348)

(5) Using the lateral distance of the effect and the length of the alteration, estimate the size of the area that is affected by the alteration. For example, if the lateral effect of the ditch is 234 m

(769 ft) and the ditch is 15.24 m (50 ft) long, the area affected is $769 \times 50 = 38{,}450\ \text{ft}^2$ (0.36 ha (0.88 acres)).

(6) Calculate the ratio of the size of all areas within the area being assessed that are affected by an alteration to the water table slope to the size of the entire assessment area. For example, if the area inside the assessment area affected by the alteration is 0.36 ha (0.88 acres), and the entire assessment area is 4 ha (10 acres), the ratio is 0.36/4 = 0.09.

(7) Multiply the ratio by 100 to obtain the percentage of the area being assessed with an altered water table slope (9 percent).

(8) Report the percentage of the area being assessed with an altered water table slope.

In western Tennessee reference wetlands, the percentage of the area being assessed with an altered water table slope ranged from 0 to 100 (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned when the percent altered area is 0 (Figure 12). As the percentage of area increases, a linearly decreasing subindex is assigned, based on the assumption that the percentage of altered area is inversely related to the capacity of the riverine wetland to maintain a characteristic subsurface hydrology.

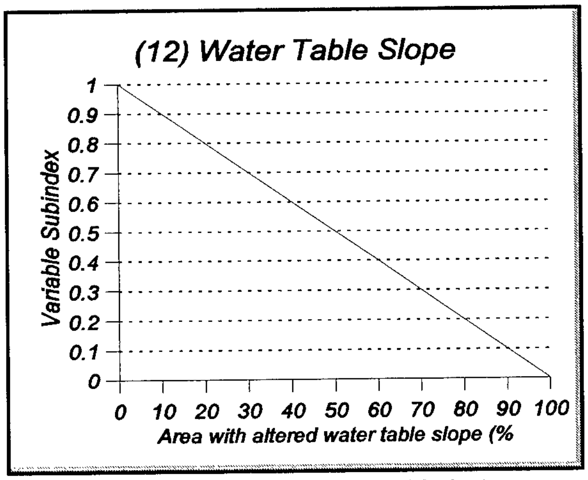

Figure 12. Function 2: Relationship between water table slope and functional capacity

Subsurface storage volume **(V_{PORE}).** This variable represents the volume of space available below the ground surface for storing water after adjusting for antecedent moisture conditions (Dunne and Leopold 1978). Like subsurface water velocity, this variable is difficult to assess rapidly. The only types of change that can be detected in a rapid assessment context are relatively gross changes in subsurface storage volume that result from activities such as agricultural, silvicultural, construction, or surface mining that significantly alter or replace the soil profile.

Percent effective soil porosity is used to quantify this variable. Use the following procedure:

(1) Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in construction projects or surface mining, or any other activities with the potential to alter

effective soil permeability. Assign a variable subindex based on the category of alteration that has occurred at the site shown in Table 12. (Note: in this particular situation, no value is assigned to the metric, rather a variable subindex is assigned directly.)

Table 12
Variable Subindices for Soils Altered by Silvicultural, Agricultural, and Construction/Mining Activities

Alteration Category	"Typical" Effective Soil Porosity After Alteration	Average Depth of Alteration Effects	Variable Subindex
Silviculture: normal activities compact surface layers and reduce permeability to a depth of about 15.2 cm (6 in.) (Aust 1994)	highly variable and spatially heterogeneous	top 15.2 cm (6 in.) of soil profile	0.7
Agricultural tillage: some surface compaction occurs as well as generally decreasing the average size of pore spaces which decreases the ability of water to move through the soil to a depth of about 15.2 cm (6 in.) (Drees et al. 1994).	highly variable and spatially heterogeneous	top 15.2 cm (6 in.) of soil profile	0.7
Construction activities/surface mining: compaction resulting from large equipment over the soil surface, cover of soil surface with pavement or fill material, or excavation and subsequent replacement of heterogeneous materials	highly variable and spatially heterogeneous	entire soil profile	0.1

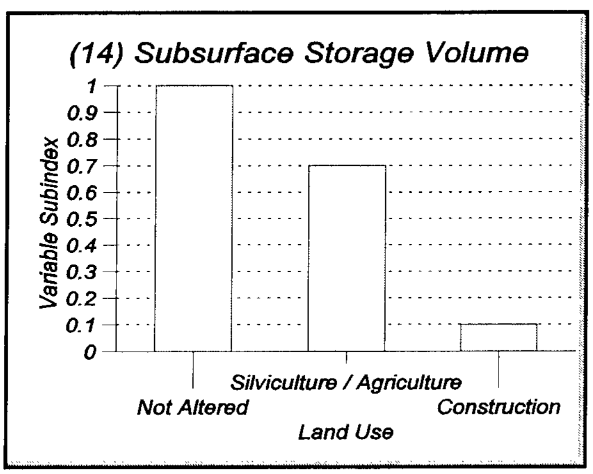

Figure 13. Function 2: Relationship between land use activities and functional capacity

In western Tennessee reference wetlands, effective soil porosity ranged from 40.5 to 47.5 percent (Appendix D). The typical concept of reference standard sites does not apply in the case of this variable. Certain soil series are found in some river systems but not in others. Thus, a subindex of 1.0 should be assigned unless the soils have been altered (Figure 13). Sites altered by agricultural (e.g., plowing or cultivation) or silvicultural activities (e.g., cutting, shearing, or skidding) were assigned a variable subindex of 0.7 (Table 12). This is based on data from Aust (1994) and Drees et al. (1994) which indicate that, as a result of these activities, soil properties are generally altered in the top 15.2 cm (6 in.) of the soil profile. This means that effective soil porosity in the lower

35.6 cm (14 in.), or 70 percent of the 50.8-cm (20-in.) soil profile is unaltered. Thus, a subindex of 0.7 is assigned. Sites altered by construction activities, surface mining, or other activities that affect the entire soil profile are assigned a subindex of 0.1, based on the fact that all soils, regardless of their effective soil porosity, provide some storage volume.

Water table fluctuation (V_{WTF}). This variable represents the upward and downward fluctuation of the water table that occurs throughout the year in riverine wetlands as a result of precipitation, evapotranspiration, groundwater movement, and flood events. As the water table drops, soil pore space becomes available for storing water below the surface. When the water table is at its highest level (typically in winter and early spring), the wetland soil is saturated. These types of fluctuations occur, to some extent, in all riverine wetland soils in western Tennessee.

Presence or absence of a fluctuating water table is used to categorize this variable. Assign a category with the following procedure.

(1) Determine whether the water table at the site fluctuates by using the following criteria (in order of decreasing accuracy and preference):

(a) groundwater monitoring well data

(b) redoximorphic features such as oxidized rhizospheres, reaction to *a,a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994; Hurt, Whited, and Pringle 1996), remembering that some redoximorphic features reflect that a soil has been anaerobic at some time in the past but do not necessarily reflect current conditions

(c) the presence of a fluctuating water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the soil survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

(2) Report water table fluctuations as present or absent.

In western Tennessee reference wetlands, the evidence of a fluctuating water table was present and absent (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned when evidence of a fluctuating water table is present (Figure 14). A subindex of zero is assigned when evidence of a fluctuating water table is absent. This is based on the assumption that if a fluctuating water table is absent (i.e., removed by the

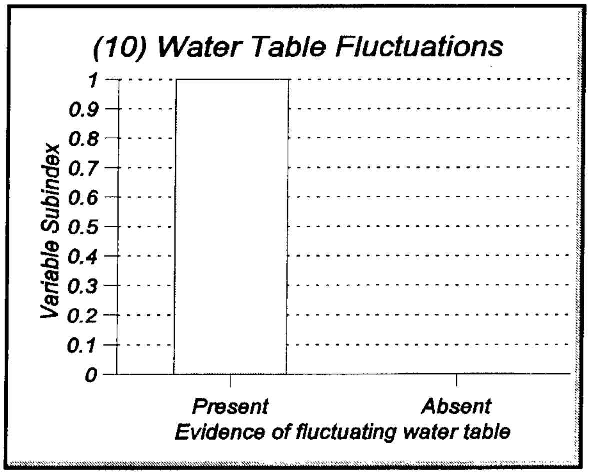

Figure 14. Function 2: Relationship between fluctuating water table and functional capacity

placement of fill, the installation of drainage ditches, drawdown by water supply wells, or by permanent inundation) then the antecedent moisture conditions have been altered, and the subsequent movement of subsurface water has been affected.

Functional capacity index

The assessment model for calculating the FCI is as follows:

$$FCI = \left[\frac{\left(V_{SOILPERM} \times V_{WTSLOPE}\right)^{1/2} + \left(\frac{V_{PORE} + V_{WTF}}{2} \right)}{2} \right] \quad (4)$$

In the model, the capacity of the riverine wetland to maintain subsurface hydrology focuses on two characteristics. The first is the effect riverine wetlands have on subsurface water as it moves from adjacent uplands to the stream channel. The second is the ability of the riverine wetland to maintain characteristic fluctuations in the water table that set up the temporal shift from saturated to unsaturated soil pore spaces necessary for storing subsurface water.

The first part of the model estimates the velocity at which subsurface water moves from the upland through the riverine wetland to the stream channel. As discussed above, this is based on Darcy's general equation, with $V_{SOILPERM}$ representing hydraulic conductivity and $V_{WTSLOPE}$ representing hydraulic gradient. In the equation, $V_{SOILPERM}$ and $V_{WTSLOPE}$ are partially compensatory, based on the assumption that they contribute equally and independently to the performance of the function (WRP in preparation, Chapter 4). The use of a geometric mean to combine these variables is consistent with the relationship defined in Darcy's general equation.

The second part of the model estimates volume for storing water below the surface of the ground and the likelihood that the water will fluctuate and provide pore space necessary for storing subsurface water. In riverine wetlands, this depends largely on maintaining characteristic seasonal fluctuations of the water table and soil porosity. V_{WTD} represents the fluctuation of the water table, and V_{PORE} represents soil porosity. These two variables are partially compensatory because they are assumed to contribute equally and independently to the performance of the function. The variables are combined using an arithmetic

mean to reduce the influence of either variable on the resulting index (WRP in preparation, Chapter 4).

The relationship between the two parts of the model is also partially compensatory because they are believed to contribute equally and independently to the performance of the function. An arithmetic mean is used to reduce the influence of relatively low values from either part of the model on the resulting FCI.

Function 3: Cycle Nutrients

Definition

Cycle Nutrients is defined as the ability of the riverine wetland to convert nutrients from inorganic forms to organic forms and back through a variety of biogeochemical processes such as photosynthesis and microbial decomposition. Potential independent, quantitative measures for validating the functional index include net annual primary productivity (gm/m^2), annual litter fall (gm/m^2), or standing stock of living and/or dead biomass (gm/m^2).

Rationale for selecting the function

The cycling of nutrients is a fundamental function that helps to maintain an adequate pool of nutrients throughout the various compartments of an ecosystem (Ovington 1965, Pomeroy 1970, Ricklefs 1990). For example, an adequate supply of nutrients in the soil profile supports primary production which makes it possible for the plant community to develop and be maintained (Bormann and Likens 1970, Whittaker 1975, Perry 1994). The plant community, in turn, provides a pool of nutrients and source of energy for secondary production and also provides the habitat structure necessary to maintain the animal community (Fredrickson 1978, Crow and MacDonald 1978, Wharton et al. 1982). Plant and animal communities serve as the source of detritus which provides nutrients and energy necessary to maintain a characteristic community of decomposers to break down organic material into simpler elements and compounds that can then reenter the nutrient cycle (Reiners 1972; Dickinson and Pugh 1974; Pugh and Dickinson 1974; Schlesinger 1977; Singh and Gupta 1977; Hayes 1979; Harmon, Franklin, and Swanson 1986; Vogt, Grier, and Vogt 1986).

Characteristics and processes that influence the function

In riverine wetlands, nutrients are stored within, and cycled between, four major compartments: (a) the soil, (b) primary producers such as vascular and nonvascular plants, (c) consumers such as animals, fungi, and bacteria, and (d) dead organic matter, such as leaf litter or woody debris, referred to as detritus. The transformation of nutrients within each compartment and the flow of nutrients between compartments are mediated by a complex variety of

biogeochemical processes. For example, plant roots take up nutrients from the soil and detritus and incorporate them into the organic matter in plant tissues. Nutrients incorporated into herbaceous or deciduous parts of plants will turn over more rapidly than those incorporated into the woody parts of plants. However, ultimately, all plant tissues are either consumed (~10 percent) or die and fall to the ground where they are decomposed by fungi and microoganisms and mineralized to again become available for uptake by plants.

Many of the processes involved in nutrient cycling, such as primary production and decomposition, have been studied extensively in wetlands (Brinson, Lugo, and Brown 1981). In forested riverine wetlands of the Southeast specifically, there is a rich literature on the standing stock, accumulation, and turnover of above-ground biomass in successional and mature stages (Brinson 1990). For example, the annual production of leaves is well documented through litterfall studies (Conner and Day 1976, Day 1979, Mulholland 1981, Elder and Cairns 1982, Brown and Peterson 1983, Conner and Day 1992). Until recently, less attention has been paid to woody (Harmon, Franklin, and Swanson 1986; Symbula and Day 1988) and below-ground (Raich and Nadelhoffer 1989, Nadelhoffer and Raich 1992) components of these systems.

The ideal approach for assessing nutrient cycling would be to measure the rate at which nutrients are transformed and transferred between compartments over the period of a year (Kuenzler et al. 1980; Brinson, Bradshaw, and Kame 1984; Harmon, Franklin, and Swanson 1986). However, the time and effort required to make these measurements are well beyond a rapid assessment procedure. The alternative is to estimate the standing stocks of living and dead biomass in each of the four compartments and assume that nutrient cycling is taking place at a characteristic level if the biomass in each compartment is similar to that in reference standard wetlands.

Description of model variables

Tree biomass (V_{TBA}). This variable represents the total mass of organic material per unit area in the trees that occupy the stratum in riverine forests. Trees are defined as woody stems ≥6 m in height and ≥10 cm in diameter at breast height (dbh) which is 1.4 m above the ground (Bonham 1989). Tree biomass is correlated with forest maturity (Brower and Zar 1984) and, in the context of this function, serves as an indication that trees are present, taking up nutrients, and producing biomass.

Tree basal area, a common measure of abundance and dominance in forest ecology that has been shown to be proportional to tree biomass (Whittaker 1975, Whittaker et al. 1974, Spurr and Barnes 1981, Tritton and Hornbeck 1982, Bonham 1989), is used to quantify this variable. Measure it with the following procedure.

(1) Measure the dbh in centimeters of all trees in a circular 0.04-ha sampling unit (Pielou 1984), hereafter called a plot.

(2) Convert each of the diameter measurements to area, sum them, and convert to square meters. For example, if 3 trees with diameters of 20 cm, 35 cm, and 22 cm were present in the plot, the conversion to square meters would be made as follows. Remembering that the diameter of a circle (D) can be converted to area (A) using the relationship $A = 1/4pD^2$, it follows that $1/4p20^2 = 314$ cm², $1/4p35^2 = 962$ cm², $1/4p22^2 = 380$ cm². Summing these values gives 314 + 962 + 380 = 1,656 cm², and converting to square meters by multiplying by 0.0001 gives 1,656 cm² × 0.0001 = 0.17 m². This computation has been simplified on the field sheets.

(3) If multiple 0.04-ha plots are sampled, average the results from all plots.

(4) Convert the results to a per hectare basis by multiplying by 25, since there are 25 0.04-ha plots in a hectare. For example, if the average value from all the sampled plots is 0.17 m², then 0.17 m² × 25 = 4.3 m²/ha.

(5) Report tree basal area in square meters per hectare.

The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units. Other plot-based or plotless methods for measuring tree basal area have been developed and may provide results that are similar to those described above (Lindsey, Barton, and Miles 1958; Suwong, Frayer, and Mogren 1971; Cox 1980; Hays, Summers, and Seitz 1981; Avery and Burkhart 1983; Green 1992).

In the flat zones of western Tennessee reference wetlands, tree basal area ranged from 0 to 64 m²/ha (Appendix D). Based on the data from reference standard sites supporting mature, fully stocked forests, a variable subindex of 1.0 is assigned when tree basal area is ≥20 m²/ha (Figure 15). At reference sites in the middle to early stages of succession, or cleared for agriculture, tree basal area decreases, and a linearly decreasing subindex down to zero at zero tree basal area is assigned. This is based on the assumption that the relationship between tree basal area and the capacity of the riverine wetland to cycle nutrients is linear. This assumption could be validated using the data from a variety of low gradient, riverine wetlands in the Southeast summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997) or by the independent, quantitative measures of function identified above.

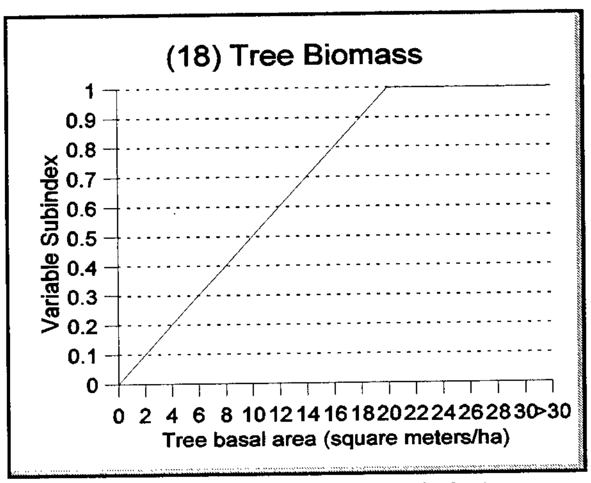

Figure 15. Function 3: Relationship between tree basal area and functional capacity

Understory vegetation biomass (V_{SSD}). This variable represents the total mass of organic material per unit area in the understory stratum of riverine forests. Understory vegetation is defined as woody stems (e.g., shrubs, saplings, and understory trees) >1 m in height and <10 cm dbh. In the context of this function, this variable serves as an indication that understory vegetation is present, taking up nutrients, and producing biomass.

Stem density in stems per hectare is used to quantify this variable. Measure it with the following procedure.

(1) Count the stems of understory vegetation in either a 0.04-ha plot or each of two 0.004-ha sampling units, hereafter called subplots, located in representative portions of each quadrant of the 0.04-ha plot. Sample using two 0.004-ha subplots if the stand is in an early stage of succession and a high density of stems makes sampling 0.04-ha plots impractical.

(2) If 0.004-ha subplots are used, average the results and multiply by 10 to obtain the value for each 0.04-ha plot.

(3) If multiple 0.04-ha plots are sampled, average the results from all 0.04-ha plots.

(4) Convert the results to a per hectare basis by multiplying by 25. For example, if the average of the 0.04-ha plots is 23 stems, then 23 × 25 = 575 stems/ha.

(5) Report shrub and sapling density as stems per hectare.

The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

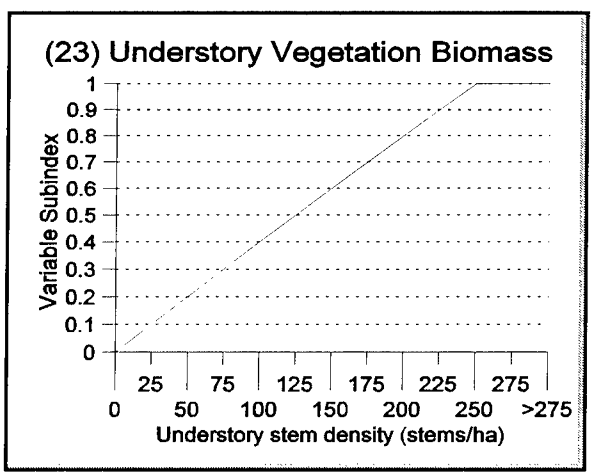

Figure 16. Function 3: Relationship between understory vegetation stem density and functional capacity

In western Tennessee reference wetlands, understory vegetation stem density ranged from 0 to 69,575 stems/ha (Appendix D). Reference standard sites had understory vegetation stem densities of between 250 and 1,475 stems/ha (Figure 16). It is presumed that understory vegetation stem density above reference standard contribute to nutrient cycling at at least the same levels as reference standard. Thus, a variable subindex of 1.0 is assigned at densities at or above 250 stems/ha. As understory stem density decreases, a linearly decreasing subindex down to 0 is

assigned at 0 stems/ha. This is based on the assumption that if understory vegetation does not exist, it does not contribute to nutrient cycling. These assumptions could be validated using the data from a variety of low gradient, riverine wetlands in the Southeast summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997) or by the independent, quantitative measures of function identified above.

Ground vegetation biomass (V_{GVC}). This variable represents the total mass of organic matter in the woody and herbaceous vegetation near the surface of the ground in riverine forests. Ground vegetation is defined as all herbaceous and woody vegetation <1 m in height. In the context of this function, this variable serves as an indicator that ground vegetation is present, taking up nutrients, and producing biomass.

Percent cover of ground vegetation is used to quantify this variable. Measure it with the following procedure.

(1) Visually estimate the percentage of the ground surface that is covered by ground vegetation by mentally projecting the leaves and stems of ground vegetation to the ground surface in each of four 1-m^2 sampling units, hereafter called subplots, placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize an area will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(2) Average the values from the four 1-m^2 subplots.

(3) If multiple 0.04-ha plots are sampled, average the results from all the 0.04-ha plots.

(4) Report ground vegetation cover as a percent.

In western Tennessee reference wetlands, ground vegetation cover ranged from 0 to 100 percent (Appendix D). In reference standard wetlands, the amount of ground vegetation was relatively small due to the low level of light that occurs near the ground surface as a result of interception by trees, saplings, and shrubs. Based on data from reference standard sites, a variable subindex of 1.0 is assigned to sites with a ground vegetation cover between 0 and 30 percent (Figure 17). As ground vegetation cover increases above 30 percent, a linearly decreasing subindex down to 0.1 at 100 percent ground vegetation cover is assigned. This is based

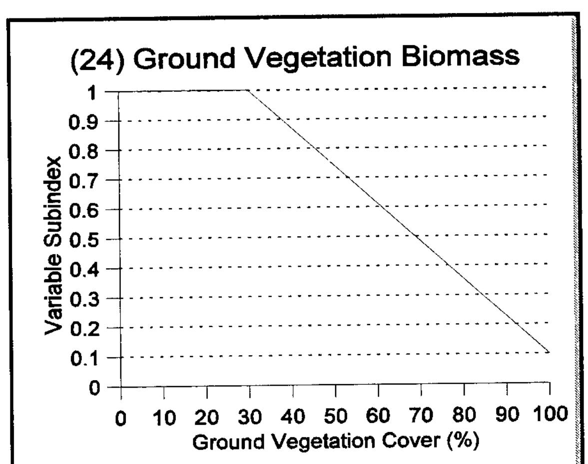

Figure 17. Function 3: Relationship between ground vegetation cover and functional capacity

on the assumption that the increase in the ground vegetation cover indicates higher levels of light at the ground surface and fewer trees, saplings, and shrubs to maintain a characteristic level of nutrient cycling. The rate at which the subindex decreases, and the selection of 0.1 as the variable subindex endpoint at 100 percent cover, is based on the assumption that the relationship between ground vegetation cover and nutrient cycling is linear and that some overstory and understory vegetation will probably be present and contributing to nutrient cycling even when the percent of ground vegetation cover is high. These assumptions could be validated using the independent, quantitative measures of function defined above.

"O" horizon biomass (V_{OHOR}). This variable represents the total mass of organic matter in the "O" horizon. The "O" horizon is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks or twigs < 0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA SCS 1993). The "O" horizon is synonymous with the term detritus or litter layer used by other disciplines. In the context of this function, this variable serves as an indicator that nutrients in vegetative organic matter are being recycled.

Percent cover of the "O" soil horizon is used to quantify this variable. Measure it with the following procedure.

(1) Visually estimate the percentage of the ground surface that is covered by an "O" horizon in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(2) Average the results from the subplots.

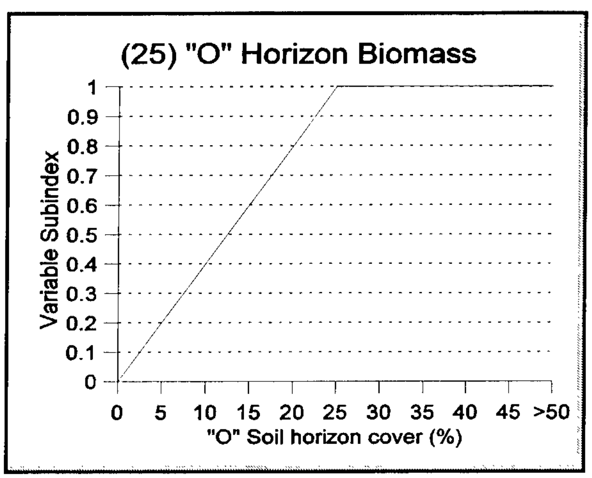

Figure 18. Function 3: Relationship between "O" soil horizon and functional capacity

(3) If multiple 0.04-ha plots were sampled, average the results from these plots.

(4) Report "O" horizon cover as a percent.

In the flats zone of western Tennessee reference wetlands, "O" horizon cover ranged from 0 to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the "O" soil horizon cover is >25 percent (Figure 18). As "O" horizon cover decreases, a linearly

decreasing subindex down to 0 at 0 percent cover is assigned. The rate at which the subindex decreases, and the selection of 0 as the subindex endpoint at 0 percent cover, is based on the assumption that the relationship between "O" soil horizon cover and nutrient cycling is linear and that a decreasing amount of biomass in the tree, sapling, shrub, and ground vegetation strata of the plant community is reflected in lower percent "O" soil horizon cover. When the "O" soil horizon percent drops to zero, the contribution of the "O" soil horizon to nutrient cycling has essentially ceased. These assumptions could be validated using the independent, quantitative measures of function defined above.

"A" horizon biomass (V_{AHOR}). This variable represents total mass of organic matter in the "A" horizon. The "A" horizon is defined as a mineral soil horizon that occurs at the ground surface, or below the "O" soil horizon, that consists of an accumulation of unrecognizable decomposed organic matter mixed with mineral soil (USDA SCS 1993). In addition, for the purposes of this procedure, in order for a soil horizon to be considered an "A" horizon, it must be at least 7.5 cm (3 in.) thick and have a Munsell color value less than or equal to 4. In the context of this function, this variable serves as an indicator that nutrients in vegetative organic matter are being recycled.

Percent cover of the "A" horizon is used to quantify this variable. Measure it with the following procedure.

(1) Estimate the percentage of the mineral soil within the top 15.2 cm (6 in.) of the ground surface that qualifies as an "A" horizon by making a number of soil observations in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. For instance, if, in each subplot, 12 soil plugs are taken and 6 show the presence of a 7.5-cm- (3-in.-) thick "A" horizon, the value of "A" horizon cover is $(6/12) \times 100 = 50$ percent. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(2) Average the results from the 1-m^2 subplots within each 0.04-ha plot.

(3) If multiple 0.04-ha plots were sampled, average the results from these plots.

(4) Report "A" horizon cover as a percent.

In western Tennessee reference wetlands, "A" horizon cover ranged from 0 to 100 percent (Appendix D). Based on reference standard sites, a variable subindex of 1.0 is assigned when the percent cover of the "A" horizon is 100 percent (Figure 19). As the percent cover of the "A" horizon decreases, a linearly decreasing subindex to zero is assigned. This is based on the assumption that the relationship between percent "A" horizon and the capacity to cycle nutrients is linear and reflects the decreasing contribution to "A" horizon

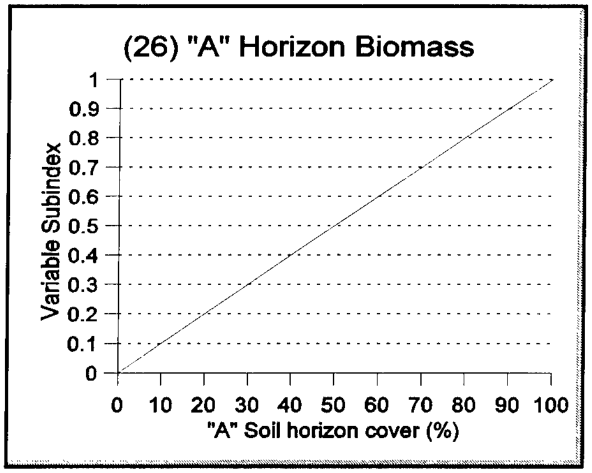

Figure 19. Function 3: Relationship between "A" soil horizon and functional capacity

biomass by the tree, sapling, shrub, and ground vegetation strata of the plant community. Sites that have been converted to agricultural crops may have low coverage of the "A" horizon due to the oxidation of the organic carbon following tillage (Ismail, Blevins, and Frye 1994).

Woody debris biomass (V_{WD}). This variable represents the total mass of organic matter contained in woody debris on or near the surface of the ground. Woody debris is defined as down and dead woody stems ≥0.25 in. in diameter that are no longer attached to living plants. Despite its relatively slow turnover rate, woody debris is an important component of food webs and nutrient cycles of temperate terrestrial forests (Harmon, Franklin, and Swanson 1986). In the context of this function, this variable serves as an indicator that the nutrients in vegetative organic matter are being recycled.

Volume of woody debris per hectare is used to quantify this variable. Measure it with the following procedure adapted from Brown (1974) and Brown, Oberheu, and Johnston (1982).

(1) Count the number of stems that intersect a vertical plane along a minimum of 2 transects located randomly and at least partially inside each 0.04-ha plot. Count the number of stems that intersect the vertical in each of three different size classes along the transect distances given below. A 6-ft transect interval is used to count stems ≥0.25 to ≤1.0 in. in diameter; a 12-ft transect interval is used to count stems >1 to ≤3 in. in diameter; and a 50-ft transect is used to count stems >3 in. in diameter.

(2) Convert stem counts for each size class to tons per acre using the following formulas. For stems in the ≥0.25 to ≤1.0 in. and >1 to ≤3 in. size classes, use the formula:

$$Tons/Acre = \frac{(11.64 \times n \times d^2 \times s \times a \times C)}{N \times l} \qquad (5)$$

where

n = total number of intersections (i.e., counts) on all transects

d^2 = squared average diameter for each size class

s = specific gravity (Birdsey (1992) suggests a value of 0.58)

a = nonhorizontal angle correction (suggested value: 1.13)

C = slope correction factor (suggested value = 1.0 since slopes in southeastern forested floodplains are negligible)

N = number of transects

l = length of transect in feet

For stems in the >3 in. size class, use the following formula:

$$Tons/Acre = \frac{(11.64 \times \Sigma d^2 \times s \times a \times C)}{N \times l} \tag{6}$$

where

n = total number of intersections (i.e., counts) on all transects

Σd^2 = the sum of the squared diameters of each intersecting stem

s = specific gravity (Birdsey (1992) suggests a value of 0.58)

a = nonhorizontal angle correction (suggested value: 1.13)

C = slope correction factor (suggested valued: 1.0 since slopes in southeastern forested floodplains are negligible)

N = number of transects

l = length of transect in feet

When inventorying large areas with many different tree species, it is practical to use composite values and approximations for diameters, specific gravities, and nonhorizontal angle corrections. For example, if composite average diameters, composite average nonhorizontal correction factors, and best approximations for specific gravities are used for the Southeast, the preceding formula for stems in the 0.25 to $\leq$1.0 in. size class simplifies to:

$$Tons/Acre = \frac{2.24(n)}{N \times l} \tag{7}$$

where

n = total number of intersections (i.e., counts) on all transects

N = number of transects

l = length of transect in feet

For stems in the >1.0 to 3.0 in. size class the formula simplifies to:

$$Tons/Acre = \frac{21.4(n)}{N \times l} \tag{8}$$

where

n = total number of intersections (i.e., counts) on all transects

N = number of transects

l = length of transect in feet

For stems in the >3.0 in. size class the formula simplifies to:

$$Tons/Acre = \frac{6.87\ (\Sigma\ d^2)}{N \times 1} \tag{9}$$

where

Σd^2 = the sum of the squared diameter of each intersecting stem

N = number of transects

l = length of transect in feet

(3) Sum the tons per acre for the three size classes and convert to cubic feet per acre:

$$Cubic\ Feet/Acre = \frac{Tons/Acre \times 32.05}{0.58} \tag{10}$$

(4) Convert cubic feet per acre to cubic meters per hectare by multiplying cubic feet per acre by 0.072.

(5) Report woody debris volume in cubic meters per hectare.

In western Tennessee reference wetlands, the volume of woody debris ranged from 0 to 138 m^3/ha (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned to sites with woody debris 25-80 m^3/ha (Figure 20). Below 25 m^3/ha the subindex decreases linearly to 0.0. This range of values included reference sites that had been converted to agriculture and had little or no woody debris, sites in early stages of succession with low volumes of woody debris, and sites in the middle stages of succession. The decrease in the

variable subindex is based on the assumption that lower volumes of woody debris indicate an inadequate reservoir of nutrients and the inability to maintain characteristic nutrient cycling over the long term. Above 80 m^3/ha the subindex also decreases linearly to 0.0 at 140 m^3/ha (the upper limit of 140 m^3/ha represents the highest volume observed in the reference sites). This is based on the assumption that increasingly higher volumes of woody debris indicate that nutrient cycles are out of balance and that high levels of nutrients are locked up in the long-term storage component and unavailable for primary production in the short term. This situation occurs after logging or catastrophic wind damage.

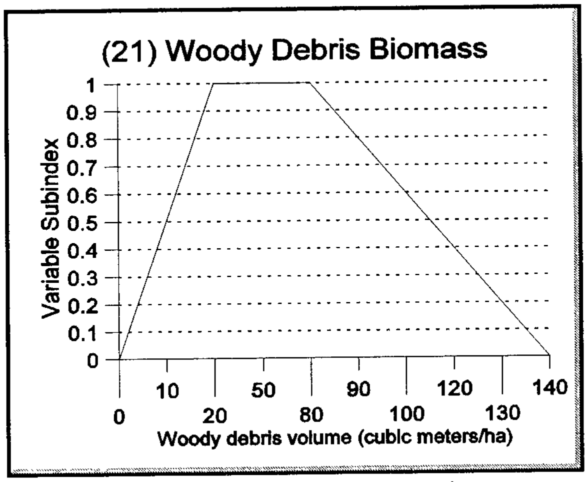

Figure 20. Function 3: Relationship between woody debris and functional capacity

Functional capacity index

The assessment model for the Cycle Nutrients function is:

$$FCI = \left[\frac{\left(\frac{V_{TBA} + V_{SSD} + V_{GVC}}{3} \right) + \left(\frac{V_{OHOR} + V_{AHOR} + V_{WD}}{3} \right)}{2} \right] \qquad (11)$$

In the model, the capacity of the riverine wetland to cycle nutrients depends on two characteristics. The first is the presence of all strata of the plant community, represented in the first part of the model by the variables V_{TBA}, V_{SSD}, and V_{GVC}. These partially compensatory variables (WRP in preparation, Chapter 4) are combined using an arithmetic mean. This is based on an assumption of equal importance for each strata of the plant community and the fact that the total loss of one of the strata (i.e., a variable subindex of 0.0) does not cause nutrient cycling to cease, just to be reduced.

The second characteristic, the presence of the long- and short-term detrital and soil components, is represented in the second part of the model by the variables V_{OHOR}, V_{AHOR}, and V_{WD}. These partially compensatory variables are averaged based on the assumption that all detrital components are of equal importance in nutrient cycling.

The two parts of the model are averaged because production and decomposition processes in nutrient cycling are considered to be interdependent and equally important. Hence a characteristic level of nutrient cycling (i.e., an FCI of 1.0) will not be achieved if nutrient cycling processes related to primary production or decomposition are reduced. An arithmetic, rather than a

geometric, mean is used in recognition of the fact that it is possible under certain situations for variable subindices to drop to 0.0 for short periods of time. For example, high velocity currents associated with overbank floods can physically remove detrital components for short periods of time. However, as long as the three strata of plant community are present, the primary production component of nutrient cycling will continue, detrital stocks will be replenished quickly, and nutrient cycling will continue at high levels.

Function 4: Remove and Sequester Elements and Compounds

Definition

Remove and Sequester Elements and Compounds is defined as the ability of the riverine wetland to permanently remove or temporarily immobilize nutrients, metals, and other elements and compounds that are imported to the riverine wetland from upland sources and via overbank flooding. In a broad sense, elements include macronutrients essential to plant growth (nitrogen, phosphorus, and potassium) and other elements such as heavy metals (zinc, chromium, etc.) that can be toxic at high concentrations. Compounds include pesticides and other imported materials. The term "removal" means the permanent loss of elements and compounds from incoming water sources (e.g., deep burial in sediments, loss to the atmosphere), and the term "sequestration" means the short- or long-term immobilization of elements and compounds. A potential independent, quantitative measure of this function is the quantity of one or more imported elements and compounds removed or sequestered per unit area during a specified period of time (e.g., $g/m^2/yr$).

Rationale for selecting the function

The role of riverine wetlands as interceptors of elements and compounds from upland or aquatic nonpoint sources is widely documented (Lowrance et al. 1984; Peterjohn and Correll 1984; Cooper, Gilliam, and Jacobs 1986; Cooper et al. 1987). Riverine wetlands in headwater and lower order streams are strategically located to intercept elements and compounds originating in the adjacent upland areas before they reach streams (Brinson 1993b). Riverine wetlands on higher order streams also have been found to remove elements from overbank floodwater (Mitsch, Dorge, and Wiemhoff 1979). The primary benefit of this function is simply that the removal and sequestration of elements and compounds by riverine wetlands reduce the load of nutrients, heavy metals, pesticides, and other pollutants in rivers and streams. This translates into better water quality and aquatic habitat in rivers and streams.

Characteristics and processes that influence the function

There are two categories of characteristics and processes that influence the capacity of riverine wetlands to remove and sequester elements and compounds. The first deals with the mechanisms by which elements and compounds are transported to the wetland, and the second deals with the structural components and biogeochemical processes involved in removal or sequestration of the elements and compounds.

Elements and compounds are imported to riverine wetlands by a variety of mechanisms and from a variety of sources. They include dry deposition and precipitation from atmospheric sources, overbank flooding, and overland flow, channelized flow, interflow, shallow groundwater flow, and colluvial material from upland sources. Some of the mechanisms, such as dry deposition and precipitation, typically account for a small proportion of the total quantity of elements and compounds imported to the riverine wetland. More importantly, these mechanisms typically are not impacted, particularly from the 404 perspective. The mechanisms that bring nutrients and compounds to the wetland from alluvial and upland sources are more important in terms of both the quantity of elements and compounds and their likelihood of being impacted.

Once nutrients and compounds arrive in the riverine wetland, they may be removed and sequestered through a variety of biogeochemical processes. Biogeochemical processes include complexation, chemical precipitation, adsorption, denitrification, decomposition to inactive forms, hydrolysis, uptake by plants, and other processes (Kadlec 1985, Faulkner and Richardson 1989, Johnston 1991). A major mechanism that contributes to removal of elements and compounds from water entering a wetland is reduction. Denitrification will not occur unless the soil is anoxic and the redox potential falls below a certain level. When this occurs, nitrate (NO_3^-) removed by denitrification is released as nitrogen gas to the atmosphere. In addition, sulfate is reduced to sulfide which then reacts with metal cations to form insoluble metal sulfides such as CuS, FeS, PbS, and others.

Another major mechanism for removal of elements and compounds is by adsorption to electrostatically charged soil particles. Clay particles and particulate organic matter are the most highly charged soil particles and contribute the most to the cation exchange capacity (CEC) of the soil. Cation exchange is the interchange between cations in solution and other cations on the surface of any active material (i.e., clay colloid or organic colloid). The sum total of exchangeable cations that a soil can adsorb is the cation exchange capacity. The CEC of a soil is a function of the amount and type of clay and the amount of organic matter in the soil. Further, organic matter is a food source for microbes involved in various microbial processes (i.e., reduction-oxidation reactions, denitrification, microbial pesticide degradation, etc.).

Nitrogen in the ammonium (NH_4^+) form may be sequestered by adsorption to clay minerals in the soil. Phosphorus can only be sequestered, not truly removed. The soluble orthophosphate ion (PO_4^{3-}) may be specifically adsorbed

("fixed") to clay and Fe and Al oxide minerals (Richardson 1985) which are generally abundant in riverine wetlands. Likewise, heavy metals can be sequestered from incoming waters by adsorption onto the charged surfaces (functional groups) of clay minerals by specific adsorption onto Fe and Al oxide minerals or by chemical precipitation as insoluble sulfide compounds. Direct measurement of concentrations of these soil components is beyond the scope of rapid assessment. However, soils with pH of 5.5 or less generally have Al oxide minerals present that are capable of adsorbing phosphorus and metals. Fe oxides are reflected in brown or red colors in surface or subsoil horizons, either as the dominant color or as redox concentrations. If the Fe oxide minerals become soluble by reduction, adsorbed phosphorus is released into solution. Annual net uptake of phosphorus by growing vegetation, although significant, usually represents a small quantity relative to other soil/sediment sinks of phosphorus (Brinson 1985). Riverine wetlands also retain nutrients and compounds by storing and cycling them among the plant, animal, detrital, and soil compartments (Patrick and Tusneem 1972; Kitchens et al. 1975; Brinson 1977; Day, Butler, and Conner 1977; Mitsch, Dorge, and Wiemhoff 1979; Yarbro 1983; Brinson, Bradshaw, and Kame 1984; Yarbro et al. 1984; Godshalk, Kleiss, and Nix in prep.).

Description of model variables

Overbank Flood Frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency is the manifestation of current conditions in the watershed and channel at the spatial scale of the riverine wetland. In the context of this function, overbank flooding is the mechanism by which nutrients and compounds are imported to the riverine wetland from alluvial sources. A characteristic return interval makes it possible for removal and sequestration processes to take place. However, overbank flooding is also important in setting up the chemical environment (oxidation/reduction potentials, pH, etc.) which mediates the removal of elements and compounds.

A fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999) is used to quantify this variable (this and other methods to quantify this variable are described in Appendix C). Overbank flood frequency is a function of discharge and channel capacity (cross-sectional area). The procedure for measuring it is described on page 33.

In western Tennessee reference standard wetlands, channel cross-sectional area is described by the regression equation $16.4 \times DA^{0.57}$. Based on the fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999), sites adjacent to rivers with areas within a factor of 2 are assigned a subindex of 1.0 (Figure 21). Sites adjacent to channels with a departure from the curve by a factor of 2 to 4 are assigned a subindex of 0.5. Sites with a departure of greater than 4 are assigned a subindex of 0.1. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the

cross-sectional area of the channel, a greater discharge is required to overtop the bank and innundate the riverine wetland. Since greater discharges occur with less frequency, elements and compounds are delivered at a rate less than that characteristic of reference standard sites. The rationale at which the subindex is scaled is based on data from the USGS gage at Bolivar for the growing season over a 67-year period, and the magnitude of scatter within the data used to develop the regional curve (Appendix C). Model validation will help refine the actual nature of this relationship.

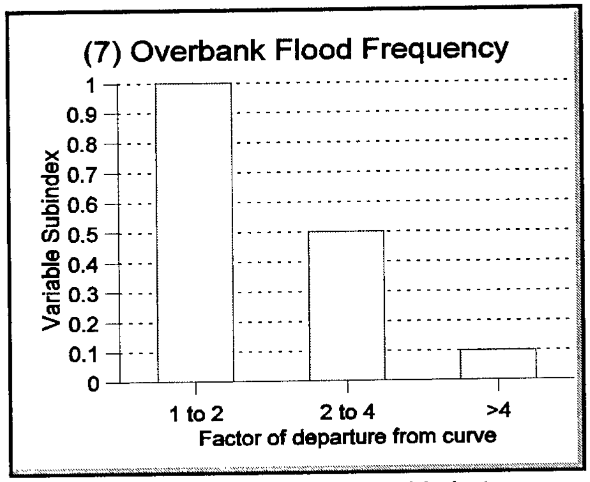

Figure 21. Function 4: Relationship between channel cross-sectional area and functional capacity

Water Table Depth (V_{WTD}). This variable represents the depth to seasonal high water table in the riverine wetland. In the context of this function, this variable indicates whether or not groundwater contributes to maintaining a hydrolgic regime that is conducive to the biogeochemical processes that remove and sequester elements and compounds.

Depth to the seasonal high water table is used to quantify this variable. Measure it with the following procedure.

(1) Determine the depth to the current seasonal high water table by using the following criteria (in order of accuracy and preference):

  (a) groundwater monitoring well data collected over several years

  (b) abundant redoximorphic features such as iron concentrations, reaction to *a,a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994; Hurt, Whited, and Pringle 1996), remembering that some redoximorphic features reflect a soil that has been anaerobic at some time in the past, but do not necessarily reflect current conditions

  (c) the presence of a seasonal high water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the soil survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

(2) Report depth to seasonal high water table in inches.

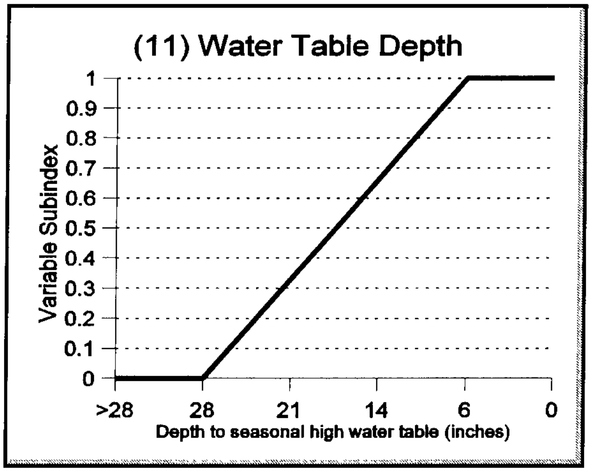

Figure 22. Function 4: Relationship between depth to seasonal high water table and functional capacity

In the flats zone of western Tennessee reference wetlands, the depth to seasonal high water table ranged from 0 to 28 in. below the surface (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 was assigned to seasonal high water table "depths" between 0 (i.e., ground surface) and 6 in. below the surface (Figure 22). As the depth to the seasonal high water table increases (i.e., is farther below the surface of the ground), the subindex decreases linearly to 0 at a depth of 24 in. This is based on the assumption that the capacity of the riverine wetland to maintain the degree of soil saturation required for characteristic biogeochemical processes including sequestering elements and compounds is dependent on a characteristic seasonal high water table near or above the surface of the ground.

Soil clay content (V_{CLAY}). This variable represents the proportion of the total charge in the top 50 cm (20 in.) of the soil profile that originates from the clay fraction or separate. One of the mechanisms that contributes to retention of elements and compounds is adsorption to charged sites on soil particles. The adsorption capacity of a soil is reflected by the CEC and anion exchange capacity (AEC) which originate from electrostatic charges on organic and mineral particles in the soil. Within the mineral fraction, most of the charge originates from clay-sized particles (<0.002 mm) because of surface area and types of minerals present in this size separate. The amount and mineralogy of the clay (i.e., whether smectite, mica, vermiculite, kaolinite, etc.) determine the total charge, either positive or negative, derived from clay particles. The pH and total concentration of ions in the soil solution within the horizon can also affect the total charge, especially for soils with high amounts of kaolinite, Fe and Al oxides, and other variable-charge components. For the purposes of the western Tennessee guidebook, we assume that clay mineralogy is relatively uniform; thus, the amount of clay within a horizon can be used to reflect the total nonorganic charge for the horizon.

Most of the impacts that riverine wetlands are subjected to do not significantly change the amount or type of clay in the soil profile. However, some impacts, such as the placement of fill material or the excavation and replacement of soil, can significantly alter the amount or type of clay and, consequently, the charge characteristics of the soil and the ability of the wetland to retain elements and compounds.

The percent difference in clay content in the top 50 cm (20 in.) of the soil profile in the assessment area is used to quantify this variable. Measure it with the following procedure.

(1) Determine if the soil in any of the area being assessed has been covered with fill material, excavated and replaced, or subjected to any other types of impact that significantly change the clay content of the top 50 cm (20 in.) of the soil profile. If no such alteration has occurred, assign the variable subindex a value of 1.0 and move on to the next variable. A value of 1.0 indicates that none of the soils in the area being assessed have an altered clay content in the top 50 cm (20 in.).

(2) If the soils in part of the area being assessed have been altered in one of the ways described above, estimate the soil texture for each soil horizon in the upper 50.8 cm (20 in.) in representative portions of these areas. Soil particle size distribution can be measured in the laboratory on samples taken from the field, or the percent of clay can be estimated from field texture determinations done by the "feel" method. Appendix C describes the procedures for estimating texture class by feel.

(3) Based upon the soil texture class, determined in the previous step, the percentage of clay is determined from the soil texture triangle. The soil texture triangle contains soil texture classes and the corresponding percentages of sand, silt, and clay which comprise each class. Once the soil texture is determined by feel, the corresponding clay percentage is read from the left side of the soil texture triangle. The median value from the range of percent clay is used to calculate the weighted average. For example, if the soil texture at the surface was a silty clay loam, the range of clay present in that texture class is 28-40 percent. A median value of 34 percent would be used for the clay percentage in that particular horizon.

(4) Calculate a weighted average of the percent clay in the altered soil by averaging the percent clay from each of the soil horizons to a depth of 50.8 cm (20 in.). For example, if the "A" horizon occurs from a depth of 0-12.7 cm (0-5 in.) and has 30 percent clay, and the "B" horizon occurs from a depth of 15.2-50.8 cm (6-20 in.) and has 50 percent clay, then the weighted average of the percent clay for the top 50.8 cm (20 in.) of the profile is $((5 \times 30) + (15 \times 50)) / 20 = 45$ percent.

(5) Calculate the difference in percent clay between the natural soil (i.e., what existed prior to the impact) and the altered soil using the following formula: percent difference = ((| % clay after alteration - % clay before alteration |) / % clay before alteration). For example, if the percentage of clay after alteration is 40 percent, and the percentage of clay before alteration is 70 percent, then $| 40 - 70 | = 30$, and $(30 / 70) = 43$ percent.

(6) Average the results from representative portions of the altered area.

(7) Multiply the percent difference for each altered area by the percent of the riverine wetland being assessed that the area represents (Column 3 in Table 13).

(8) Sum values in Column 4 and multiply by 100 to obtain the percent difference (last row in Table 13).

(9) Report the percent difference in the soil clay content in the area being assessed.

Table 13
Calculating Percent Difference of Clay in Soils of Wetland Assessment Area

Area Description	Average Percent Difference in Clay Content in the Area	Percent of Area Being Assessed Occupied by the Area	Column 2 Multiplied by Column 3
Altered area 1	43% (0.43)	10% (0.10)	0.043
Altered area 2	60% (0.50)	10% (0.10)	0.05
Unaltered area	0.0% (0)	80% (0.80)	0
Percent difference = (sum of column 4) × 100 = 9.3 %			0.093

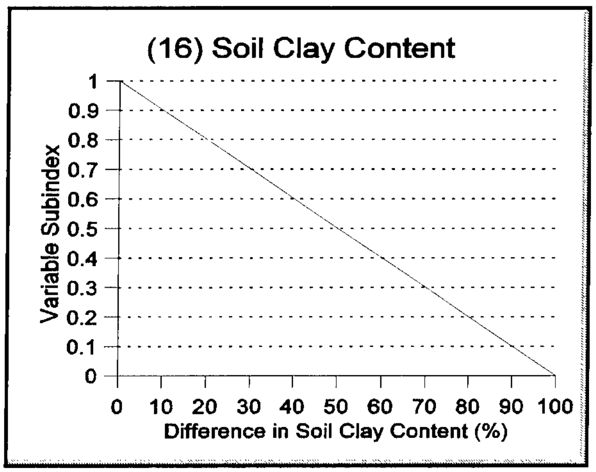

Figure 23. Function 4: Relationship between percent difference in soil clay and functional capacity

In western Tennessee reference wetlands, the percent difference in clay content from the normal condition in all soils examined was zero (Appendix D). No alteration to the soil clay content is assigned a subindex value of 1.0. If soil clay content has changed (through fill, mining, excessive sedimentation, etc.), a linearly decreasing subindex down to 0 at 100 percent alteration is assigned (Figure 23). This is based on the assumption that, as the percent difference in soil clay content increases, the capacity of the soil to adsorb cations decreases linearly. These assumptions can be validated using an independent, quantitative measure of function identified above.

Redoximorphic features (V_{REDOX}). This variable represents the reduction and oxidation history of the soil in a riverine wetland. Hydric soil indicators include redoximorphic features, accumulation of organic matter, or other indicators discussed in the National Technical Committee for Hydric Soils publication on hydric soil indicators (Hurt, Whited, and Pringle 1996). The presence of hydric soil indicators implies adequate soil saturation for a sufficient duration to induce reduction in the top 30.5 cm (12 in.) of the soil profile. It is assumed that soil reduction in the upper part has more influence on the wetland ecosystem than at greater depths. The presence of redoximorphic features anywhere in the top 30.5 cm (12 in.) is positive evidence that the soil is undergoing periodic reduction and oxidation, a major mechanism in the removal

of elements and compounds in the soil profile. Most of these redoximorphic features are associated with reduction and oxidation of Fe which occur at a redox potential between that needed for reduction of nitrate (denitrification) and that needed for sulfate reduction. Thus, the presence of redoximorphic features in the soil indicates that denitrification has occurred. However, this provides no information on the formation of sulfides. Sulfide odor could be used as an indicator, but this will vary seasonally as the water table fluctuates.

The presence of hydric soil indicators varies widely among and within soils depending on season, frequency and duration of saturation, amount and type of organic C, and other factors. Consequently, no attempt is made to develop a relationship between this variable and functional capacity based on the degree or expression of hydric soil indicators. Rather, the variable is designed to indicate whether or not reduction occurs sometime during the year in most years, based on the presence or absence of redoximorphic features in the soil.

The presence or absence of redoximorphic features is used to categorize this variable. Determine the appropriate category with the following procedure.

(1) Observe the top 30.5 cm (12 in.) of the soil profile and determine if redoximorphic features, accumulation of organic matter, or other hydric soil indicators are present or absent.

(2) Report redoximorphic features as present or absent.

In western Tennessee reference wetlands, redoximorphic features ranged from present to absent (Appendix D). Based on the presence of redoximorphic features at all reference standard sites, a variable subindex of 1.0 was assigned to the presence of redoximorphic features (Figure 24). Sites where redoximorphic features are absent are assigned a subindex of 0.1 based on the assumption that, even in the absence of redoximorphic features, reduction sometimes may place.

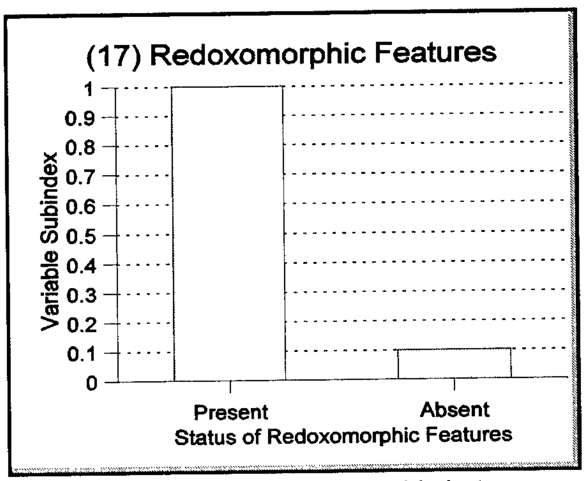

Figure 24. Function 4: Relationship between status of redoximorphic features and functional capacity

"O" horizon biomass (V_{OHOR}). This variable represents the total mass of organic matter in the "O" horizon. The "O" horizon is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks or twigs < 0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA SCS 1993). The "O" horizon is synonymous with the term detritus or litter layer used by other disciplines. In the context of this function, the "O" horizon represents a component of the organic matter which can sequester imported elements and compounds by adsorption.

Percent cover of the "O" soil horizon is used to quantify this variable. Measure it with the procedure described on page 56.

In the flats zone of western Tennessee reference wetlands, percent "O" horizon cover ranged from 0 to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the "O" soil horizon cover is >25 percent (Figure 25). As "O" horizon cover decreases, a linearly decreasing subindex down to 0 at 0 percent cover is assigned. The rate at which the subindex decreases is based on the assumption that the relationship is linear. When the percent of "O" soil horizon drops to zero, sequestration by organic matter has essentially ceased. These assumptions could be validated using the independent, quantitative measures of function defined above.

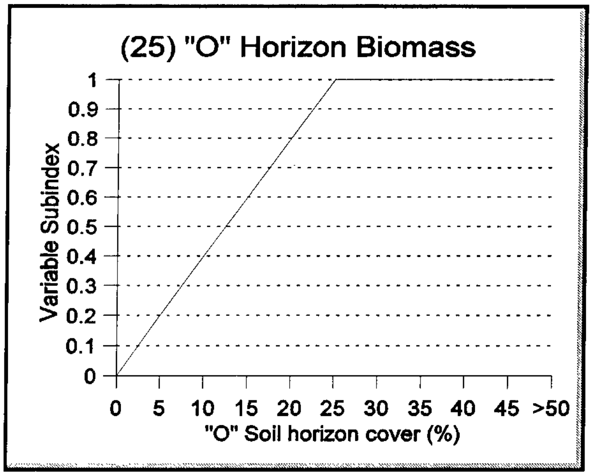

Figure 25. Function 4: Relationship between "O" soil horizon and functional capacity

"A" horizon biomass (V_{AHOR}). This variable represents the total mass of organic matter in the "A" horizon. The "A" horizon is defined as a mineral soil horizon that occurs at the ground surface, or below the "O" soil horizon, and consists of an accumulation of unrecognizable decomposed organic matter mixed with mineral soil (USDA SCS 1993). In addition, for the purposes of this procedure, in order for a soil horizon to be considered an "A" horizon, it must be at least 7.6 cm (3 in.) thick and have a Munsell color value less than or equal to 4. In the context of this function, the "A" horizon represents another reservoir of organic matter which is available to adsorb elemental compounds.

Percent cover of the "A" soil horizon is used to quantify this variable. Measure it with the procedure described on page 57.

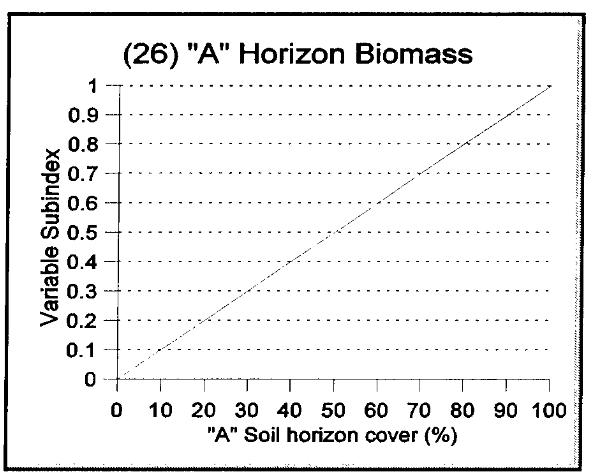

Figure 26. Function 4: Relationship between "A" soil horizon and functional capacity

In western Tennessee reference wetlands, "A" horizon cover was 100 percent. There are, however, sites in the reference domain that have disturbed "A" horizons or even lack one completely due to construction, sand mining, etc. Based on reference standard sites, a variable subindex of 1.0 is assigned when the percent cover of the "A" horizon is >100 percent (Figure 26). As the percent cover of the "A" horizon decreases, a linearly decreasing subindex down to 0 at 0 percent cover is assigned. This is based

on the assumption that the relationship between percent "A" horizon and the capacity to remove and sequester elements and compounds is linear. Sites that have been converted to agricultural crops may have low coverage of the "A" horizon due to the oxidation of the organic carbon following tillage (Ismail, Blevins, and Frye 1994).

Functional capacity index

The assessment model for deriving the FCI is as follows:

$$FCI = \left[\left(\frac{V_{FREQ} + V_{WTD}}{2} \right) \times \left(\frac{V_{CLAY} + V_{REDOX} + V_{OHOR} + V_{AHOR}}{4} \right) \right]^{1/2} \tag{12}$$

In the first part of the model, recurrence interval (V_{FREQ}) indicates whether or not elements and compounds are being imported from the stream or river. Seasonal high water table depth (V_{WTD}) indicates whether or not groundwater contributes to maintaining a hydrolgic regime that is conducive to the biogeochemical processes that remove and sequester elements and compounds. The two variables are partially compensatory based on the assumption that they are independent and contribute equally to performance of the function. The two variables are combined using an arithmetic mean because elements and compounds will continue to be imported to the wetland even if the value of the V_{WTD} subindex drops to 0.0.

In the second part of the model, four variables, all indicating different mechanisms for removing or sequestering imported elements and compounds, are assumed to be independent and to contribute equally to performance of the function. V_{CLAY}, V_{AHOR}, and V_{OHOR} represent the adsorptive capacity of soils due to clays and organic matter, while V_{REDOX} represents the reducing environment and level of microbial activity needed for this function to occur.

The two parts of the equation are combined using a geometric mean because if either subpart of the equation zeros, then the functional capacity should also drop to zero. If elements and compounds are no longer imported to the riverine wetland, or if all the mechanisms that exist within the wetland for removing and sequestering elements and compounds are absent, then the riverine wetland has no capacity to remove elements and compounds.

Function 5: Retain Particulates

Definition

Retain Particulates is defined as the capacity of a wetland to physically remove and retain inorganic and organic particulates >0.45 μm (Wotton 1990) from the water column. The particulates may originate from either onsite or

offsite sources. A potential independent, quantitative measure of this function is the amount of particulates retained per unit area per unit time (i.e., $g/m^2/yr$).

Rationale for selecting the function

Retention of particulates is an important function because sediment accumulation contributes to the nutrient capital of the riverine wetland. Deposition of inorganic particulates also increases surface elevation and changes topographic complexity, which has hydrologic, biogeochemical, and habitat implications. Particulate organic matter and woody debris also may be retained for decomposition, nutrient recycling, and detrital food web support. This function also reduces stream sediment load that would otherwise be transported downstream.

Characteristics and processes that influence the function

Three primary modes of water and sediment movement can be identified: (a) in-channel flow, (b) overbank flooding, and (c) overland flow (Molinas et al. 1988). Flooding during overbank flow is the primary mode for transporting inorganic particulates to floodplain wetlands. The movement of sediment can be described by the processes of initiation of motion, transport, and deposition. Initiation of motion is primarily a function of the energy available (e.g., falling raindrops or flowing water) and the nature of the sediment (e.g., more energy being required for bigger particles, and soils with well-developed root systems being more resistant to erosion). Once sediment particles are set in motion, the capacity of flows to transport sediment is primarily a function of water velocity, depth of flow, floodplain slope, and the size of the particles being carried (e.g., sand versus silt). Scour and deposition processes are adjustments to maintain a balance between amounts of sediment that overbank flows can carry and the amount of sediment transported. If sediment load exceeds the ability of the water flow to carry the load (i.e., transport capacity), deposition occurs. On the other hand, if the sediment transport capacities exceed the amount of sediment being carried then scour is likely to occur.

In overbank flooding situations, water velocities drop sharply as water overtops the bank and spreads onto the floodplain. The reductions in transport capacity result in deposition. Under reference standard conditions, low gradient, riverine, forested wetlands have well-developed canopy and litter layers that absorb kinetic energy of precipitation (i.e., less energy to detach sediment). They also have high surface roughness coefficients that produce low velocities and low transport capacities thus retaining sediment within the wetland and producing deposition from overbank flows. However, much of the velocity reduction, and consequent reduction in transport capacity that facilitate deposition, is accounted for by floodwaters spreading out over large, flat areas rather than by the roughness of the site (Molinas et al. 1988). The same hydrodynamics that facilitate sedimentation may also capture and retain organic particulates. For example, deposition of silt by winter floods following autumn

litterfall appears to reduce the potential for leaves to become suspended by currents and exported (Brinson 1977). The Retention of Particulates function contrasts with Cycling of Nutrients and Removal and Sequestration of Imported Elements and Compounds because the emphasis is on physical processes (e.g., sedimentation and particulate removal). The processes involved in Retention of Particulates are similar to those involved in Temporary Storage of Surface Water; consequently, the variables for these two functions are identical. However, the rationale for including the variables differentiates the two functions.

Description of model variables

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency is the manifestation of current conditions in the watershed and channel at the spatial scale of the riverine wetland. In the context of this function, overbank flooding is the mechanism by which particulates are imported to the riverine wetland from alluvial sources.

A fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999) is used to quantify this variable (this and other methods to quantify this variable are described in Appendix C). Overbank flood frequency is a function of discharge and channel capacity (cross-sectional area). The procedure for measuring it is described on page 33.

In western Tennessee reference standard wetlands, channel cross-sectional area is described by the regression equation $16.4 \times DA^{0.57}$. Based on the fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999), sites adjacent to rivers with areas within a factor of 2 are assigned a subindex of 1.0 (Figure 27). Sites adjacent to channels with a departure from the curve by a factor of 2 to 4 are assigned a subindex of 0.5. Sites with a departure of greater than 4 are assigned a subindex of 0.1. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the cross-sectional area of the channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur with less frequency, particulates are retained at a rate less than that characteristic of reference standard sites. The rationale at which the subindex is scaled is based on data from the USGS gage at Bolivar for the growing season

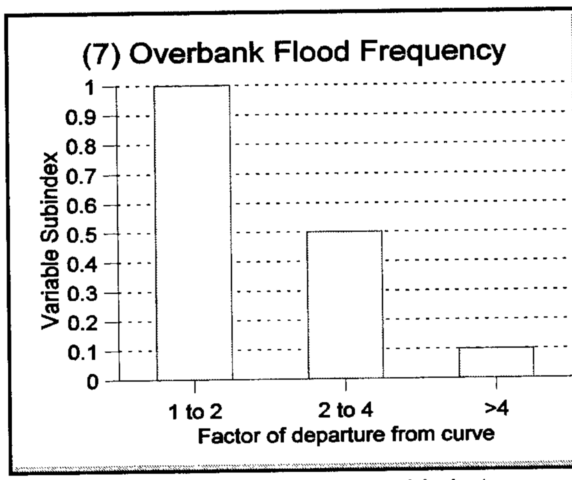

Figure 27. Function 5: Relationship between channel cross-sectional area and functional capacity

over a 67-year period, and the magnitude of scatter within the data is used to develop the regional curve (Appendix C). Model validation will help refine the actual nature of this relationship.

Floodplain storage volume (V_{STORE}). This variable represents the volume of space available for flood water to spread out, thus reducing transport capacity and allowing particulates to settle out during overbank flood events. In western Tennessee, the loss of volume is usually a result of levees, roads, or other man-made structures reducing the effective width of the floodplain. Consequently, this variable is designed to detect alterations that result from these types of structures.

The ratio of floodplain width to channel width is used to quantify this variable. The procedure for measuring this variable is described on page 35.

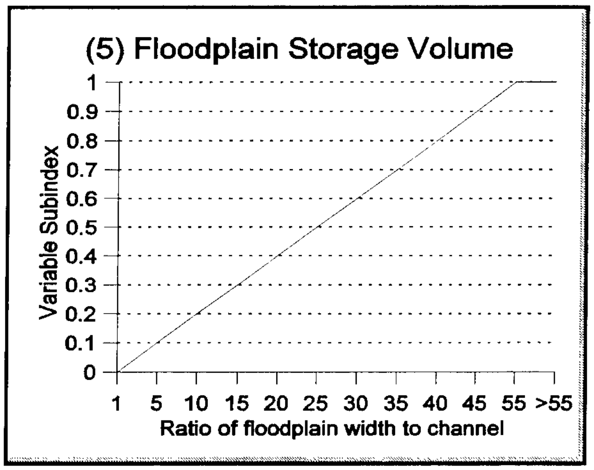

Figure 28. Function 5: Relationship between the ratio of floodplain width to channel width and functional capacity

In western Tennessee reference wetlands, the ratio of floodplain width to channel width ranged from 35 to 175 (Appendix D). Based on the range of values at reference standard wetlands, a variable subindex of 1.0 is assigned to ratios ≥53 (Figure 28). Smaller ratios are assigned a linearly decreasing subindex down to 0 at a ratio of 1. This is based on the assumption that the ratio of floodplain width to channel width is linearly related to the capacity of riverine wetlands to temporarily store surface water and retain particulates.

Floodplain slope (V_{SLOPE}). This variable represents the slope of the floodplain adjacent to the riverine wetland being assessed. The relationship between slope and the retention of particulates is based on the proportional relationship between slope and velocity in Manning's equation (Equation 1). In laymen's terms, the flatter the slope, the slower water moves through the riverine wetland. In the context of this function, this variable is designed to detect when the characteristic floodplain slope has been changed as a result of surface mining or other activities that significantly alter floodplain slope.

The percent floodplain slope is used to quantify this variable. The procedure for measuring this variable is described on page 36.

In western Tennessee reference wetlands, floodplain slopes ranged from 0.01-0.09 percent (Appendix D). Reference standard wetland sites had floodplain slopes of 0.04 percent. A variable subindex of 1.0 is assigned to floodplain slopes ≤0.09 percent (Figure 29). In the western Tennessee reference domain,

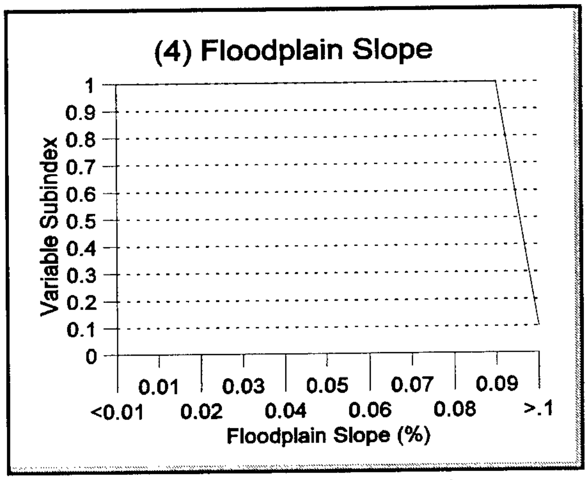

Figure 29. Function 5: Relationship between floodplain slope and functional capacity

no large-scale floodplain alterations have occurred, thus this variable normally will have a subindex value of 1.0.

Floodplain roughness (V_{ROUGH}). This variable represents the resistance to the flow of surface water resulting from physical structure on the floodplain. The relationship between roughness and the velocity of surface water flow is expressed by Manning's equation, which indicates that, as roughness increases, velocity decreases and the ability of the water column to keep sediment particles entrained also decreases (Equation 1). Several factors contribute to roughness, including the soil surface, surface irregularities (e.g., micro- and macrotopographic relief), obstructions to flow (e.g., stumps and coarse woody debris), and resistance due to vegetation structure (trees, saplings, shrubs, and herbs). Depth of flow is also an important consideration in determining roughness because, as water depth increases, obstructions are overtopped and cease to be a source of friction or turbulence. Thus the roughness coefficient often decreases with increasing depth.

Manning's roughness coefficient *(n)* is used to quantify this variable. The procedure for measuring this variable is described on page 37.

In the flats zone of western Tennessee reference wetlands, Manning's roughness coefficients ranged from 0.035 to 0.24 (Appendix D). These values are based on setting n_{BASE} to 0.03 and adjustment values for the topographic relief component (n_{TOPO}) that ranged from 0.005-0.01, the obstructions component (n_{OBS}) that ranged from 0.01-0.05, and the vegetation component (n_{VEG}) that ranged from 0.05-0.15. Based on the range of values at reference standard sites, a variable subindex of 1.0 is assigned to Manning's roughness coefficients between 0.055 and 0.19 (Figure 30). Sites with higher roughness coefficients are also assigned a subindex of 1.0 based on the assumption that the increased roughness does not significantly increase retention time. Lower roughness coefficients were assigned a linearly decreasing subindex down to 0.5 at ≤0.03 (the roughness attributed to the soil).

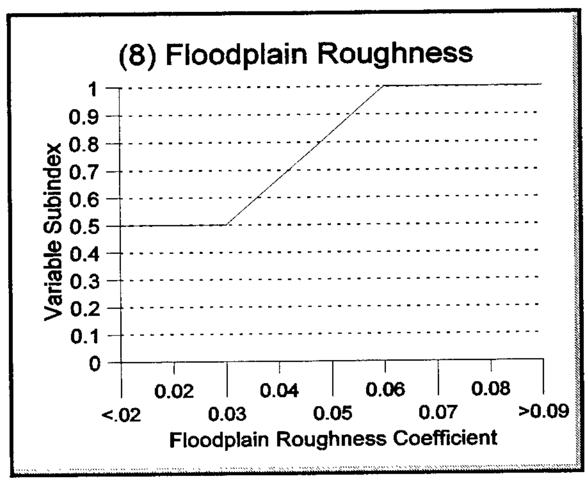

Figure 30. Function 5: Relationship between floodplain roughness and functional capacity

Functional capacity index

The assessment model for calculating the FCI is as follows:

$$FCI = \left[\left(V_{FREQ} \times V_{STORE} \right)^{1/2} \times \left(\frac{V_{SLOPE} + V_{ROUGH}}{2} \right) \right]^{1/2} \tag{13}$$

In this model, the capacity of the riverine wetland to retain particulates depends on two characteristics, the ability of water to get to the site and the ability of the wetland to reduce the velocity of surface water moving through the site. In the first part, the V_{FREQ} variable indicates whether or not changes in the watershed or channel have altered the recurrence interval compared to reference standard sites. The V_{STORE} variable indicates whether or not structural alterations or fill have reduced the volume available for temporarily storing surface water and, thus, retaining particulates.

The relationship between the variables is partially compensatory, and they are assumed to contribute equally and independently to the performance of the function (WRP in preparation, Chapter 4). As the subindices for V_{FREQ} or V_{STORE} decrease, the FCI also decreases. If the subindex for V_{STORE} drops to zero, the FCI will also drop to zero because a geometric mean is used to combine V_{FREQ} and V_{STORE}. This simply means that as the frequency of inundation decreases or if the floodplain is greatly constricted by levees or roads, retention of particulates is reduced or eliminated.

In the second part of the model, V_{ROUGH} and V_{SLOPE} reflect the ability of the wetland to reduce the velocity of water moving through it. These variables also are partially compensatory and assumed to be independent and to contribute equally to the performance of the function. In this case however, the variables are combined using an arithmetic mean. Generally, this mathematical operation reduces the influence of lower value subindices on the FCI (Smith and Wakeley 1998).

Function 6: Export Organic Carbon

Definition

Export Organic Carbon is defined as the capacity of the wetland to export the dissolved and particulate organic carbon produced in the riverine wetland. Mechanisms include leaching of litter, flushing, displacement, and erosion. An independent quantitative measure of this function is the mass of carbon exported per unit area per unit time (g/m^2/yr).

Rationale for selecting the function

The high productivity and close proximity of riverine wetlands to streams make them important sources of dissolved and particulate organic carbon for aquatic food webs and biogeochemical processes in downstream aquatic habitats (Vannote et al. 1980; Elwood et al. 1983; Sedell, Richey, and Swanson 1989). Dissolved organic carbon is a significant source of energy for the microbes that form the base of the detrital food web in aquatic ecosystems (Dahm 1981, Edwards 1987, Edwards and Meyers 1986). Evidence also suggests that the particulate fraction of organic carbon imported from uplands or produced in situ is an important energy source for shredders and filter-feeding organisms (Vannote et al. 1980).

Structural characteristics and processes that influence the function

Wetlands can be characterized as open or closed systems depending on the degree to which materials are exchanged with surrounding ecosystems (Mitch and Gosselink 1993). Riverine wetlands normally function as open systems, primarily for two reasons. First, riverine wetlands occur in valley bottoms adjacent to stream channels. Since stream channels are the lowest topographic position in the landscape, water and sediments pass through the riverine wetlands as gravity moves them toward the stream channel. Second, under natural conditions, low-gradient riverine wetlands are linked to the stream channel through overbank flooding. In the case of the Export of Organic Carbon function, the latter reason is of greatest importance.

Watersheds with a large proportion of riverine and other wetland types have generally been found to export organic carbon at higher rates than watersheds with fewer wetlands (Mulholland and Kuenzler 1979; Brinson, Lugo, and Brown 1981; Elder and Mattraw 1982; Johnston, Detenbeck, and Niemi 1990). This is attributable to several factors, including: (a) the large amount of organic matter in the litter and soil layers that comes into contact with surface water during inundation by overbank flooding, (b) relatively long periods of inundation and, consequently, contact between surface water and organic matter, thus allowing for significant leaching, (c) the ability of the labile carbon fraction to be rapidly leached from organic matter when exposed to water (Brinson, Lugo, and Brown 1981), and (d) the ability of floodwater to transport dissolved and particulate organic carbon from the floodplain to the stream channel.

Description of model variables

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. In the context of this function, overbank flooding is the mechanism by which organic carbon is exported from riverine wetlands.

A fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999) is used to quantify this variable (this and other methods to quantify this variable are described in Appendix C). Overbank flood frequency is a function of discharge and channel capacity (cross-sectional area). The procedure for measuring it is described on page 33.

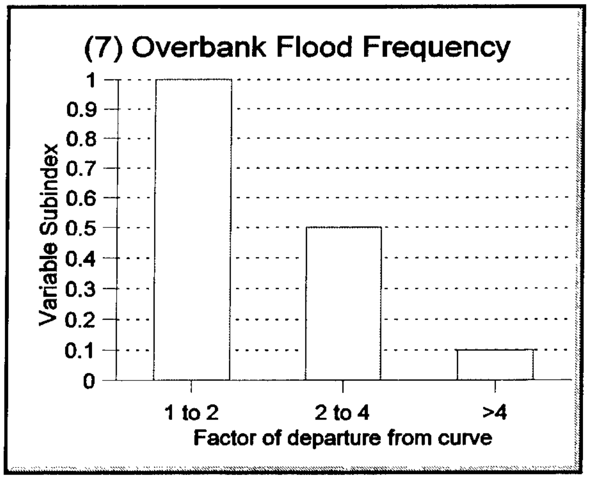

Figure 31. Function 6: Relationship between channel cross-sectional area and functional capacity

In western Tennessee reference standard wetlands, channel cross-sectional area is described by the regression equation $16.4 \times DA^{0.57}$. Based on the fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999), sites adjacent to rivers with areas within a factor of 2 are assigned a subindex of 1.0 (Figure 31). Sites adjacent to channels with a departure from the curve by a factor of 2 to 4 are assigned a subindex of 0.5. Sites with a departure of greater than 4 are assigned a subindex of 0.1. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the cross-sectional area of the channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur with less frequency, organic carbon is exported at a rate less than that characteristic of reference standard sites. The rationale at which the subindex is scaled is based on data from the USGS gage at Bolivar for the growing season over a 67-year period, and the magnitude of scatter within the data is used to develop the regional curve (Appendix C). Model validation will help refine the actual nature of this relationship.

Surface water connections ($V_{SURFCON}$). This variable represents the internal network of shallow surface water channels that usually connect the riverine wetland to the stream channel on low gradient riverine floodplains. Typically, these channels intersect the river channel through low spots in the natural levee. When water levels are below channel full, these channels serve as the route for surface water, and the dissolved and particulate organic matter it carries, as it moves from the floodplain to the stream channel. This same network of channels routes overbank floodwater to riverine wetlands during the early stages of overbank flooding.

This variable is designed to indicate, at a relatively coarse level of resolution, when project impacts reduce or eliminate the surface water connection between the riverine wetland and the adjacent stream channel. Levee construction and side-cast dredging are typical project impacts that reduce or eliminate these surface water connections and, as a result, reduce the export of organic carbon.

The percentage of the linear distance of stream reach that has been altered is used to quantify this variable. Measure it with the following procedure.

(1) Conduct a visual reconnaissance of the area being assessed and the adjacent stream reach. Estimate what percent of this stream reach has been modified with levees, side-cast materials, or other obstructions that reduce the exchange of surface water between the riverine wetland being assessed and the stream channel.

(2) Report percent of the linear distance of the stream reach that has been altered to the extent that surface water connections no longer exist.

In western Tennessee reference wetlands, the percentage of the linear distance of stream reach that had been altered ranged from 0 to 100 percent (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 was assigned when surface connections are unaltered (Figure 32). A variable subindex of 1.0 is assigned when zero percent of the stream reach is altered. As the percentage of the altered stream reach increases, a decreasing subindex is assigned down to 0 when 100 percent of the stream reach is altered. This is based on the assumption that the relationship between surface water connections and carbon export is linear.

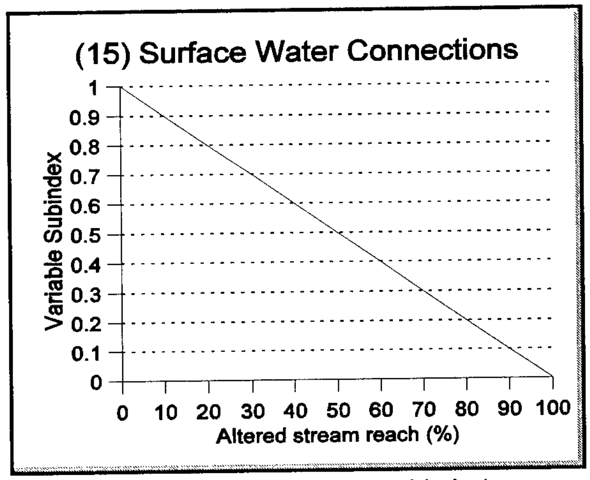

Figure 32. Function 6: Relationship between altered stream reach and functional capacity

"O" horizon biomass (V_{OHOR}). This variable represents the total mass of organic matter in the "O" horizon. The "O" horizon is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks or twigs < 0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA SCS 1993). The term "O" horizon is synonymous with the terms detritus and litter layer used by other disciplines. In the context of this function, the "O" horizon represents organic carbon available for export.

Percent cover of the "O" soil horizon is used to quantify this variable. The procedure for measuring it is described on page 56.

In the flats zone of western Tennessee reference wetlands, "O" horizon cover ranged from 0 to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the "O" soil horizon cover is >25 percent (Figure 33). As "O" horizon cover decreases, a linearly decreasing subindex down to 0 at 0 percent cover is assigned. The rate at which the subindex decreases, and the selection of 0 as the subindex endpoint at 100 percent cover, is based on the assumption that the relationship between

"O" soil horizon cover and organic carbon export is linear and that a decreasing amount of biomass in the tree, sapling, shrub, and ground vegetation strata of the plant community is reflected in lower percent "O" soil horizon cover. When the "O" soil horizon percent drops to zero, organic carbon export has essentially ceased. These assumptions could be validated using the independent, quantitative measures of function defined above.

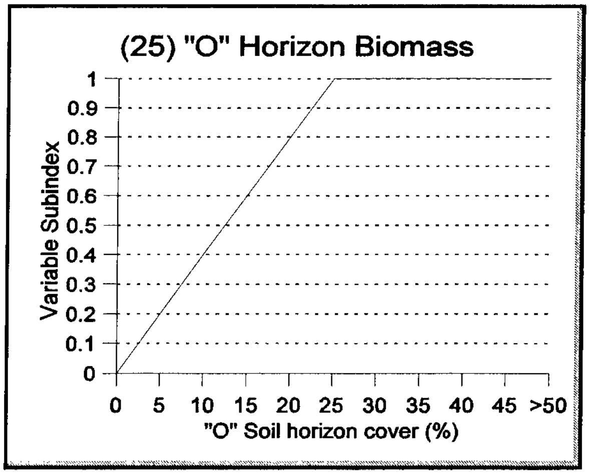

Figure 33. Function 6: Relationship between "O" soil horizon and functional capacity

Woody debris biomass (V_{WD}). This variable represents the total mass of organic matter contained in woody debris on or near the surface of the ground. Woody debris is defined as down and dead woody stems ≥0.25 in. in diameter that are no longer attached to living plants. Despite its relatively slow turnover rate, woody debris is an important component of food webs and nutrient cycles of temperate terrestrial forests (Harmon, Franklin, and Swanson 1986) and, in the context of this function, contributes to exported organic carbon.

Volume of woody debris per hectare is used to quantify this variable. The procedure for measuring it is described on page 58.

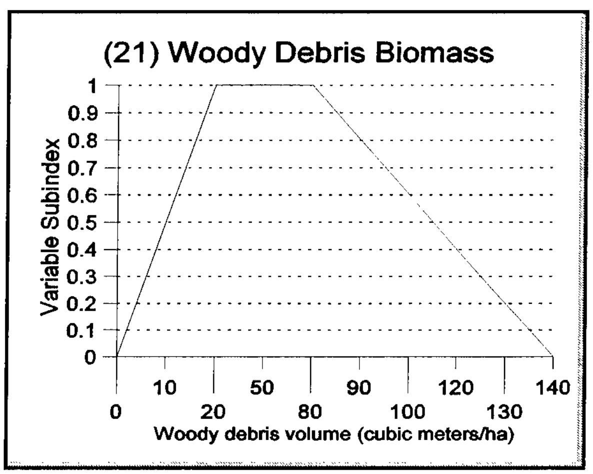

Figure 34. Function 6: Relationship between woody debris and functional capacity

In the flats zone of western Tennessee reference wetlands, the volume of woody debris ranged from 0 to 138 m^3/ha (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned to sites with woody debris 20-80 m^3/ha (Figure 34). Below 20 m^3/ha the subindex decreases linearly to 0.0.

This range of values included reference sites that had been converted to agriculture and had little or no woody debris, sites in early stages of succession with low volumes of woody debris, and sites in the middle stages of succession with moderate volumes. The decrease in the variable subindex is based on the assumption that lower volumes of woody debris indicate an inadequate reservoir of organic carbon and an inability to contribute to organic carbon export. Above 80 m^3/ha the subindex decreases linearly to 0.0 at 140 m^3/ha (the highest value observed in the reference set). This is based on the assumption that increasingly

higher volumes of woody debris, resulting from logging, will result in abnormally high levels of carbon.

Functional capacity index

The assessment model for calculating the FCI is as follows:

$$FCI = \left[\left(V_{FREQ} \times V_{SURFCON} \right)^{1/2} \times \left(\frac{V_{OHOR} + V_{WD}}{2} \right) \right]^{1/2} \tag{14}$$

In the first part of this model, the variables V_{FREQ} and $V_{SURFCON}$ reflect whether the mechanisms for exporting organic carbon from the riverine wetland are in place. The two variables are averaged by taking the geometric mean because without flooding or surface water connections to the channel, organic carbon export could be reduced significantly or cease altogether.

In the second subpart of the equation, the two important sources of dissolved and particulate organic carbon, V_{OHOR} and V_{WD}, are averaged by taking the arithmetic mean because either subpart is independently capable of significantly reducing the amount of carbon being exported. If the organic matter source of the carbon is not present, carbon export will not occur. Similarly, if the transport vector is absent, carbon export will decrease or cease.

Function 7: Maintain Characteristic Plant Community

Definition

Maintain Characteristic Plant Community is defined as the capacity of a riverine wetland to provide the environment necessary for a characteristic plant community to develop and be maintained. In assessing this function, one must consider both the extant plant community as an indication of current conditions and the physical factors that determine whether or not a characteristic plant community is likely to be maintained in the future. Potential independent, quantitative measures of this function, based on vegetation composition/ abundance, include similarity indices (Ludwig and Reynolds 1988) or ordination axis scores from detrended correspondence analysis or other multivariate technique (Kent and Coker 1995). A potential independent quantitative measure of this function, based on both vegetation composition and abundance as well as environmental factors, is ordination axis scores from canonical correlation analysis (ter Braak 1994).

Rationale for selecting the function

The ability to maintain a characteristic plant community is important because of the intrinsic value of the plant community and the many attributes and processes of riverine wetlands that are influenced by the plant community. For example, primary productivity, nutrient cycling, and the ability to provide a variety of habitats necessary to maintain local and regional diversity of animals (Harris and Gosselink 1990) are directly influenced by the plant community. In addition, the plant community of a riverine wetland influences the quality of the physical habitat and the biological diversity of adjacent rivers by modifying the quantity and quality of water (Elder 1985; Gosselink, Lee, and Muir 1990) and through the export of carbon (Bilby and Likens 1979; Hawkins, Murphy, and Anderson 1982).

Characteristics and processes that influence the function

A variety of physical and biological factors determine the ability of a riverine wetland to maintain a characteristic plant community. One could simply measure the extant plant community and assume that the wetland was performing the function at a characteristic level if the composition and structure were similar to reference standard wetlands. However, there are potential problems with this approach because of the dynamic nature of plant communities. In particular, woody plants respond relatively slowly to changes in the environment and, consequently, the structure and composition of the plant community may not reflect recent changes in the environmental conditions at a site (Shugart 1987). For example, it can take decades for changes in hydrologic regime to be reflected in the structure and composition of the forest canopy. Herbaceous species respond more quickly to changes in the environment, but using the herbaceous community as an indicator of environmental change is complicated by the fact that herbaceous communities may respond similarly to both natural temporal cycles, such as drought, or permanent changes in environmental conditions resulting from anthropogenic alteration. Thus, relying solely on the extant plant community as an indicator of the capacity of the wetland to perform this function may not accurately reflect current environmental conditions and the capacity of a riverine wetland to maintain a characteristic plant community over the long term.

A rich literature describes the environmental factors that influence the occurrence of plant communities in low gradient, riverine wetlands (Robertson, Weaver, and Cavanaugh 1978; Robertson, McKenzie, and Elliot 1984; Wharton et al. 1982; Robertson 1992; Smith 1996; Messina and Conner 1997; Hodges 1997). The most important factors that have been identified include hydrologic regime and soil type. The problem with using these factors to measure extant conditions is that, because of annual and seasonal variation, it can be difficult to assess their status during a single visit to a wetland site. For example, depending on the season of the year, the water table in many riverine wetlands could range from well below the ground surface to 2 or more meters above the ground surface. Some indicators, such as bryophyte-lichen lines, integrate conditions

over long periods of time, but, like woody vegetation, these indicators often lag or may be insensitive to short-term changes in the condition. Thus, environmental factors alone may not provide an accurate indication of the capacity of the wetland to perform this function. For these reasons, this function is assessed using variables that reflect both the composition and structure of the extant plant community and environmental factors that influence the capacity of a riverine wetland to maintain a characteristic plant community.

Description of model variables

Tree biomass (V_{TBA}). This variable represents the total mass of organic material per unit area in the tree stratum. Trees are defined as woody stems ≥6 m in height and ≥10 cm in diameter at breast height (dbh) which is 1.4 m above the ground (Bonham 1989). Tree biomass is correlated with forest maturity (Brower and Zar 1984) and, in the context of this function, serves as an indicator of plant community structure.

Tree basal area is used to quantify this variable. Measure it with the procedures described on page 52.

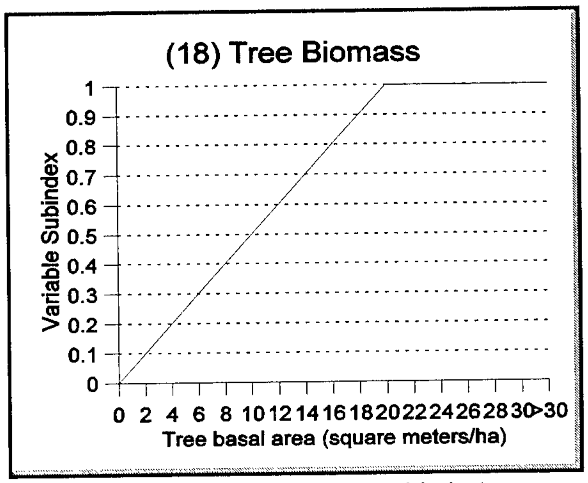

Figure 35. Function 7: Relationship between tree basal area and functional capacity

In western Tennessee reference wetlands, tree basal area ranged from 0 to 64 m^2/ha. (Appendix D). Based on the data from reference standard sites supporting mature and fully stocked forests, a variable subindex of 1.0 is assigned when tree basal area is ≥20 m^2/ha (Figure 35). At reference sites that have been cleared or are in middle to early stages of succession, tree basal area is less, and, consequently, a linearly decreasing subindex down to zero at zero tree basal area is assigned. This is based on the assumption that the relationship between tree basal area and the capacity of the riverine wetland to maintain a characteristic plant community is linear. This assumption could be validated with data from a variety of low gradient, riverine wetlands in the Southeast, summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997), or by the independent, quantitative measures of function identified above.

Tree density (V_{TDEN}). This variable represents the number of trees per unit area in riverine wetlands. Trees are defined as woody stems ≥6 m in height and ≥10 cm dbh. In most forested systems, tree stem density and basal area increase rapidly during the early successional phase. Thereafter, tree density decreases, and the rate at which basal area increases diminishes as the forest reaches mature

steady-state conditions (Spurr and Barnes 1981). In the context of this function, tree density serves as an indicator of plant community structure.

The density of tree stems per hectare is used to quantify this variable. Measure it with the following procedure.

(1) Count the number of tree stems in a circular 0.04-ha plot.

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 20 stems, then $20 \times 25 = 500$ stems/ha.

(4) Report tree density in stems/hectare.

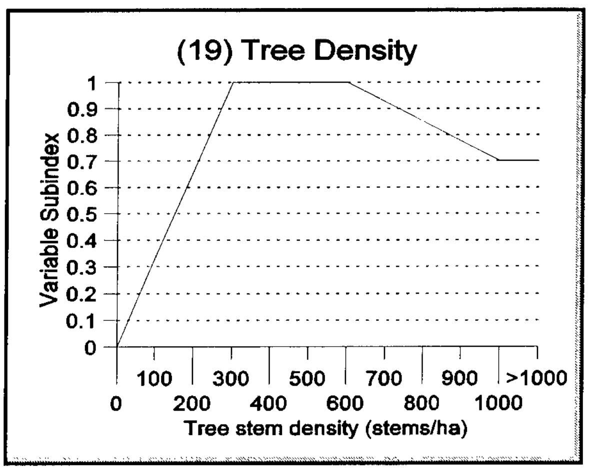

Figure 36. Function 7: Relationship between tree density and functional capacity

In western Tennessee reference wetlands, tree stem density ranged from 0 to 1,350 stems/ha (Appendix D). Based on the range of values at reference standard sites, a variable subindex of 1.0 is assigned when tree stem densities are between 300 and 600 stems/ha. (Figure 36). At sites that have been cleared for agricultural or other activities where tree stem density is 0, a subindex of 0 is assigned. As tree stem densities gradually increase during the early and mid-stages of succession, a linearly increasing subindex is assigned up to 1.0 at 300 stems/ha. As secondary succession continues, stem densities often exceed 1,000 stems/ha and a linearly decreasing subindex down to 0.7 at ≥1,000 stems/ha is assigned. This is based on the assumption that the relationship between tree stem density and the capacity of the riverine wetland to maintain a characteristic plant community is linear. This assumption could be validated by analyzing the relationship between tree stem density and the capacity to maintain a characteristic plant community using the data from a variety of low gradient riverine wetlands in the Southeast, summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997).

Plant species composition (V_{COMP}). Plant species composition represents the diversity of plants in riverine wetlands. In general, healthy, mature forest stands support higher species diversity in all strata than do younger stands. Ideally,

plant species composition would be determined with intensive sampling of woody and herbaceous species in all vegetation strata. Unfortunately, the time and taxonomic expertise required to accomplish this are not available in the context of rapid assessment. Thus, the focus here is on the dominant species in each vegetation stratum.

Percent concurrence with the dominant species in each vegetation stratum is used to quantify this variable. Measure it with the following procedure.

(1) Identify the dominant species in the canopy, understory vegetation, and ground vegetation strata using a modified 50/20 rule.[1] For the purposes of this guidebook, species comprising at least 10 percent relative abundance was used instead of 20 percent. Use tree basal area to determine abundance in the canopy stratum, understory vegetation density to determine abundance in the understory stratum, and ground vegetation cover to determine abundance in the ground vegetation stratum. To apply the modified 50/20 rule, rank species from each stratum in descending order of abundance. Identify dominants by summing the relative abundances beginning with the most abundant species in descending order until 50 percent is exceeded. Additional species with ≥10 percent relative abundance should also be considered as dominants. Accurate species identification is critical for determining the dominant species in each plot. Sampling during the dormant season may require a high degree of proficiency in identifying tree bark or dead plant parts. Users who do not feel confident in identifying plant species in all strata should get help with plant identification.

(2) For each vegetation stratum, calculate percent concurrence by comparing the list of dominant plant species from each stratum to the list of dominant species for each stratum in reference standard wetlands (Table 14). For example, if all the dominants from the area being assessed occur on the list of dominants from reference standard wetlands, then there is 100 percent concurrence. If 3 of the 5 dominant species of trees from the area being assessed occur on the list, then there is 60 percent concurrence.

(3) Average the percent concurrence from all three strata.

(4) Report concurrence of species dominants across all strata as a percent.

In western Tennessee reference wetlands, percent concurrence with dominant species ranged from 0 to 100 percent (Appendix D). Based on the data from reference standard sites supporting mature and fully stocked forests, a variable subindex of 1.0 is assigned when concurrence with dominant species is 100 percent (Figure 37). As percent concurrence decreases, a linearly decreasing subindex down to zero is assigned based on the assumption that the relationship

[1] Memorandum, 6 March 1992, Office, Chief of Engineers, Clarification of Use of the 1987 Delineation Manual.

Table 14
Dominant Species by Vegetation Strata by Zone in Reference Standard Sites in Western Tennessee

Zone	Tree	Shrub/Sapling	Ground Vegetation
Depression	*Nyssa aquatica*	*Carpinus caroliniana*	*Cornus foemina*
	Quercus lyrata	*Fraxinus pennsylvanica*	*Itea virginica*
	Taxodium distichum	*Nyssa aquatica*	*Saururus cernuus*
	Carya aquatica	*Quercus lyrata*	*Smilax rotundifolia*
		Itea virginica	*Peltandra virginica*
		Cornus foemina	
		Carya aquatica	
		Planera aquatica	
		Taxodium distichum	
Flat	*Carya glabra*	*Carpinus caroliniana*	*Arundinaria gigantea*
	Fraxinus pennsylvanica	*Carya glabra*	*Carex* spp.
	Liquidambar styraciflua	*Liquidambar styraciflua*	*Lobelia cardinalis*
	Quercus nigra	*Ulmus rubra*	*Smilax rotundifolia*
	Quercus michauxii	*Ulmus americana*	*Toxicodendron radicans*
	Quercus pagodaefolia	*Fraxinus pennsylvanica*	*Impatiens capensis*
	Quercus phellos	*Liquidambar styraciflua*	*Bignonia capreolata*
	Ulmus americana	*Quercus nigra*	*Boehmeria cylindrica*
		Quercus michauxii	*Aster simplex*
		Quercus pagodaefolia	*Vitis rotundifolia*
		Quercus phellos	*Vitis* spp.
Ridge	*Liquidambar styraciflua*	*Asimina triloba*	*Asimina triloba*
	Carya glabra	*Carpinus caroliniana*	*Arundinaria gigantea*
	Quercus alba	*Carya glabra*	*Boehmeria cylindrica*
	Quercus michauxii	*Carya ovata*	*Carex* spp.
	Quercus pagodaefolia	*Quercus nigra*	*Chasmanthium latifolium*
	Quercus phellos	*Ulmus americana*	*Toxicodendron radicans*
	Carya ovata	*Nyssa sylvatica*	*Bignonia capreolata*
	Quercus nigra	*Fagus grandifolia*	*Vitis rotundifolia*
	Ulmus americana	*Quercus shumardii*	*Vitis* spp.
	Nyssa sylvatica	*Ulmus rubra*	*Smilax rotundifolia*

(Continued)

Table 14 (Concluded)			
Zone	**Tree**	**Shrub/Sapling**	**Ground Vegetation**
Ridge (Continued)	*Fagus grandifolia*	*Liquidambar styraciflua*	*Onoclea sensibilis*
	Quercus shumardii	*Carya glabra*	
	Ulmus rubra	*Quercus alba*	
		Quercus michauxii	
		Quercus pagodaefolia	
		Quercus phellos	

Notes:
Overlap of dominant species among zones may occur and is acceptable.
Species listed in the tree and shrub/sapling layers also may occur in the ground vegetation layer, but were not listed because of space.

between plant species composition and the capacity of the riverine wetland to maintain a characteristic plant community is linear.

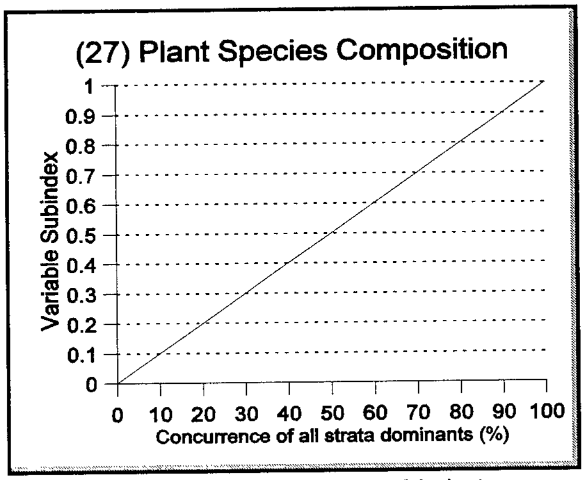

Figure 37. Function 7: Relationship between percent concurrence of all strata dominants and functional capacity

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency is a manifestation of current conditions in the watershed and channel at the spatial scale of the riverine wetland. In the context of this function, overbank flood frequency serves as an indication that a characteristic hydrologic regime to which the plant community is adapted is in place.

A fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999) is used to quantify this variable (this and other methods to quantify this variable are described in Appendix C). Overbank flood frequency is a function of discharge and channel capacity (cross-sectional area). The procedure for measuring it is described on page 33.

In western Tennessee reference standard wetlands, channel cross-sectional area is described by the regression equation $16.4 \times DA^{0.57}$. Based on the fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999), sites adjacent to rivers with areas within a factor of 2 are assigned a subindex of 1.0 (Figure 38). Sites adjacent to channels with a departure from the curve by a factor of 2 to 4 are assigned a subindex of 0.5. Sites with a departure of greater than 4 are assigned a subindex of 0.1. This is based on the assumption that, where entrenchment, channelization, or levees effectively increase the cross-sectional area of the channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur with less frequency, the plant community is expected to be different than that characteristic of reference standard sites. The rationale at which the subindex is scaled is based on data from the USGS gage at Bolivar for the growing season over a 67-year period, and the magnitude of scatter within the data is used to develop the regional curve (Appendix C). Model validation will help refine the actual nature of this relationship.

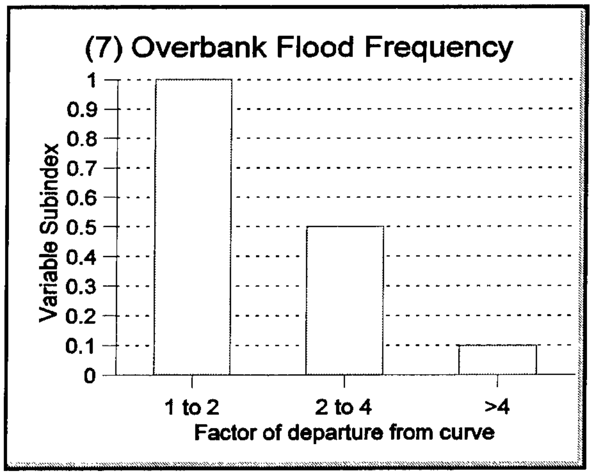

Figure 38. Function 7: Relationship between channel cross-sectional area and functional capacity

Water table depth (V_{WTD}). This variable represents the depth to seasonal high water table in the riverine wetland. In the context of this function, this variable indicates that plant communities adapted to a seasonal high water table characteristic of much of the floodplain will develop and be maintained.

Depth to the seasonal high water table is used to quantify this variable. The procedure for measuring this variable is described on page 65.

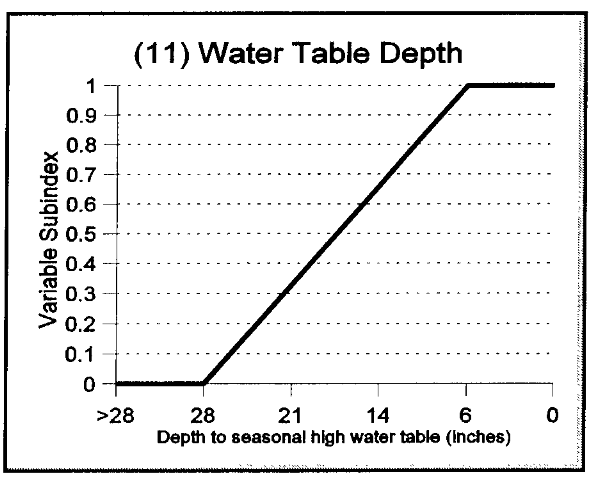

Figure 39. Function 7: Relationship between depth to seasonal high water table and functional capacity

In western Tennessee reference wetlands, the depth to seasonal high water table ranged from 0 to 28 in. below the surface (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 was assigned to seasonal high water table "depths" between 0 (i.e., ground surface) and 6 in. below the ground (Figure 39). As the depth to the seasonal high water table increases (i.e., is farther below the surface of the ground) the subindex decreases linearly to 0 at a depth of 28 in. This is based on the assumption that the capacity of the riverine wetland to

maintain the degree of soil saturation required for characteristic biogeochemical processes and plant and animal communities is dependent on maintaining a characteristic seasonal high water table near or above the surface of the ground.

Soil integrity ($V_{SOILINT}$). This variable is defined as the integrity of the soils within the area being assessed. Soil integrity is defined as the degree to which a soil approximates the natural undisturbed soil originally found at the site with respect to structure, horizonation, organic matter content, and biological activity. Soil is the medium on which the plant community develops and is maintained. Altering the properties of soil through anthropogenic activities (e.g., fill, excavation, plowing, compaction) has the potential to affect the structure and composition of the plant community.

It is difficult in a rapid assessment context to assess soil integrity for two reasons. First, there are a variety of soil properties contributing to integrity that must be measured (i.e., structure, horizonation, texture, bulk density). Second, the spatial variability of soils within riverine wetlands makes it difficult to collect the number of samples necessary to adequately characterize a site. Therefore, the approach used here is to assume that soil integrity exists where evidence of alteration is lacking. Stated another way, if the soils in the assessment area do not exhibit any of the characteristics associated with alteration, it is assumed that soils are similar to those occurring in the reference standard wetlands and have the potential to support a characteristic plant community.

The field measure of this variable is the proportion of the assessment area with altered soils. Measure it with the following procedure.

(1) Determine if any of the soils in the area being assessed have been altered. In particular, look for alteration to a normal soil profile. For example, absence of an "A" horizon, presence of sediment deposition, fill material, or other types of impact that significantly alter soil integrity.

(2) If no altered soils exist, assign the variable subindex a value of 1.0. This indicates that all of the soils in the assessment area are similar to soils in reference standard sites.

(3) If altered soils exist, determine what percent of the assessment area has soils that have been altered.

(4) Report the percent of the assessment area with altered soils.

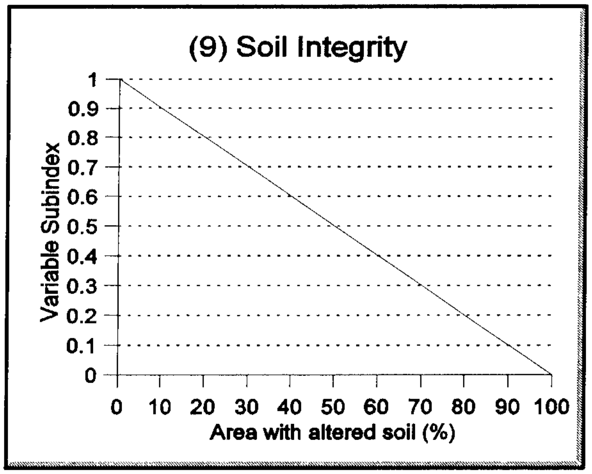

Figure 40. Function 7: Relationship between soil integrity and functional capacity

In western Tennessee reference wetlands, the percent of area with altered soils ranged from 0 to 100 percent (Appendix D). Based on the values from reference standard sites, a variable subindex of 1.0 was assigned when the percent of area with altered soils was 0 (Figure 40). As the percentage of area with altered soils increases, a linearly decreasing subindex down to 0 at 100 percent alteration is assigned. This is based on the assumption that, as the percentage of altered soils increases, the capacity of the soil to support a characteristic plant community decreases linearly.

Functional capacity index

The assessment model for deriving the FCI is as follows:

$$FCI = \left[\frac{\left(\frac{V_{TBA} + V_{TDEN}}{2}\right) + V_{COMP}}{2} \times \frac{F_{SOILINT} + V_{FREQ} + V_{WTD}}{3} \right]^{1/2} \qquad (15)$$

In the first part of the model, V_{TBA} and V_{TDEN} are averaged to provide an indication of the structural maturity of the stand. This result is then averaged with V_{COMP} to provide an indication of how similar the plant community is to reference standard conditions in terms of structure and species composition. For example, a stand with low basal area (6 m^2/ha) and high tree density (800-1,000/ha) is indicative of an immature stand and would receive a lower FCI. A stand with higher basal area (>18 m^2/ha) and lower density of trees (500 trees/ha) represents a relatively mature stand and would receive a higher FCI.

In the second part of the equation, the abiotic factors that influence the current or future composition and structure of the plant community are considered. The V_{FREQ}, V_{WTD}, and $V_{SOILINT}$ variables, which are partially compensatory and assumed to be equal and independent, are averaged using an arithmetic mean.

The two parts of the equation are considered to be independent and are averaged using a geometric mean based on the assumption that both structure and species composition and abiotic factors contribute equally to the maintenance of a characteristic plant community. If the subindices for the variables in either part of the model decrease, there will be a reduction in the FCI.

Function 8: Provide Habitat for Wildlife

Definition

Provide Habitat for Wildlife is defined as the ability of a riverine wetland to support the wildlife species that utilize riverine wetlands during some part of their life cycles. The focus of attention, however, is on the avifauna component of habitat based on the assumption that, if conditions are appropriate to support the full complement of avian species found in reference standard wetlands, the requirements of other animal groups (e.g., mammals, reptiles, arthropods, annelids, and amphibians) will be met. A potential independent, quantitative measure of this function is a similarity index calculated from species composition and abundance (Odum 1950, Sorenson 1948).

Rationale for selecting the function

Riverine floodplains and the wetlands associated with them are used extensively by terrestrial, semiaquatic, and aquatic animals to complete their life histories. The performance of this function ensures habitat for a diversity of vertebrate organisms, contributes to secondary production, maintains complex trophic interactions, and provides access to and from wetlands for completion of aquatic species life cycles. Performance of this function also provides refugia and habitat for wide-ranging or migratory birds and conduits for dispersal of species to other areas. Habitat requirements for individual species, and even groups of similar species, sometimes are highly specialized; however, most wildlife and fish species found in riverine floodplains depend on certain common characteristics such as hydroperiod, topography, forest composition and structure, and proximity to other habitats.

Characteristics and processes that influence the function

In riverine, low gradient wetlands, hydrology in the form of flooding is one of the major factors influencing wildlife habitat quality. Flooding helps sustain the forest community upon which most of the fauna depend and provides the vector for aquatic organisms to access the wetland. Many of these aquatic organisms are utilized as a food source by birds, mammals, reptiles, and amphibians. Access to the floodplain may be direct or through surface channels. Natural or man-made levees may restrict surface connections to wetlands during low flood years; however, extensive areas of a river corridor may be flooded during significant rainfall or snowmelt events, allowing unrestricted access to and across the floodplain.

Low gradient, riverine wetlands are extremely important habitats to numerous fish species. Wharton et al. (1982) provided an overview of fish use of bottomland hardwoods in the Piedmont and eastern Coastal Plain and stated that at least 20 families and up to 53 species of fish use various portions of the

floodplain for foraging and spawning. The Ictaluridae (catfish), Centrarchidae (sunfish), Lepisosteidae (gar), Percidae (perch), and Catostomidae (sucker) families were the most abundant. Baker and Killgore (1994) studied larval and adult fishes in the Cache River drainage in Arkansas and found even more species. They identified 56 different species in the river system and speculated that the actual number exceeds 60. The Percidae, Cyprinidae (minnow), and Aphredoderidae (monotypic) were the dominants.

Most of the species identified by Baker and Killgore (1994) exploit floodplain habitats at some time during the year; many for spawning and rearing. The authors investigated differential habitat use by larval and juvenile fishes and found that the oak-dominated habitats which constituted the bulk of the Cache River floodplain contained significantly more individuals than either oxbows or the channel itself. A few (10) species were most common in the oxbows; relatively few larval fish were found in the channel. These findings highlight the importance of floodplain habitats to the fish of low-gradient river systems such as the Cache.

Overbank flooding is necessary in affording access to riverine wetlands by anadromous or adfluvial fishes that use floodplain habitats to complete portions of their life histories such as spawning and rearing (Lambou 1990, Baker and Killgore 1994). The temporal periodicity and magnitude of flooding may have direct bearing on strengths of year classes. Lambou (1959) suggested that fish depend on annual fluctuations in water level to limit intra- and interspecific competition for food, space, and spawning grounds. Baker and Killgore (1994) found that the larval fish catch was much higher in a year with extensive, continuous flooding than in a year when flooding was less extensive and sporadic. Thus, regular overbank flooding and connectivity through channels are critical components to consider relative to a site-specific evaluation of fish habitat.

In addition to flooding itself, the complex environments of floodplains are of significance to fishes. Wharton et al. (1982) listed numerous examples of fish species being associated with certain portions of the floodplain. Baker, Killgore, and Kasul (1991) noted that the different microhabitats on the floodplain typically supported different fish assemblages from those of the channel. Baker and Killgore (1994) stated that "the structurally complex environment of irregularly flooded oak-hickory forests provide optimum habitat for many wetland fishes."

Riverine floodplains often contain a mosaic of habitat types that vary temporally and spatially. The pattern of types present in an area at a given time is one of the major determinants of its capacity to provide habitat for wildlife. In unaltered riparian areas, the floodplain often is comprised of topographically distinct features that reflect the hydrogeological processes that have occurred there (Mitsch and Gosselink 1993). Flats, ridges, swales, and oxbows support distinctive plant communities or "zones" (Wharton et al. 1982). In addition to the variability resulting from hydrogeological processes, forested floodplain wetlands vary in terms of the successional stages present on the landscape. Even

in unharvested forested wetlands, considerable variability may occur as a result of natural processes. For example, windthrow, herbivory, diseases, and insect outbreaks all affect the forest community and are capable of altering both age and species composition (Wharton et al. 1982).

Several authors including Fredrickson (1978) and Wharton et al. (1982) have documented that mature hardwood forests associated with low gradient, riverine wetlands support a rich diversity of animal life. In fact, several studies have shown that both bird species richness and bird species diversity are higher in such riparian habitats than in many adjacent habitats (Dickson 1978, Stauffer and Best 1980, Szaro 1980). Dickson (1978) found breeding bird densities in riparian zones to be 2 to 4 times higher than in upland habitats in the same area.

The principal reason that riverine forested wetlands support such a high diversity of terrestrial and semiaquatic wildlife is that they are floristically and hydrologically complex (Wharton et al. 1982) and (in mature systems) structurally diverse in the vertical plane (Hunter 1990). This structural diversity (layering) provides a myriad of habitat conditions for animals and allows numerous species to coexist in the same area (Schoener 1986). For example, some species of birds utilize various parts of the forest canopy whereas others are associated with the understory (Cody 1985, Wakeley and Roberts 1996). MacArthur and MacArthur (1961) documented the positive relationship between the vertical distribution of foliage (termed foliage height diversity) and avian diversity, and other researchers have since corroborated their findings. Hunter (1990) provided a good overview of the importance of structure to wildlife and noted examples of other faunal groups (mammals, reptiles, and insects) that also partition resources in a similar manner.

The composition of the plant community found in the wetland is also an important factor relative to utilization by some wildlife species. These floodplain forests commonly are extremely diverse and may contain hundreds of species. Wharton et al. (1982) listed over 50 species of trees alone, but members of the genus *Quercus* (the oaks) commonly are of overriding significance to wildlife. This significance is due to their producing acorns (sometimes called mast) which are among the most important items in the diet of many wildlife species. Some of the animals that depend on mast include the gray squirrel (*Sciurus carolinensis*), eastern wild turkey (*Meleagris gallopavo*), and wood duck (*Aix sponsa*) (U.S. Forest Service 1980). Reinecke et al. (1989) noted that acorns make up the bulk of the diet of wood ducks during most years and of mallards (*Anas platyrhynchos*) during years of good mast production. Because these two species are the most abundant ducks in the Mississippi Alluvial Valley (Reinecke et al. 1989), having a significant number of oaks in the community, especially those from the red oak group, is very important. While oaks provide the bulk of the hard mast utilized by wildlife in southern forested wetlands, hickories (*Carya* spp.) and American beech (*Fagus grandifolia*) are very important also, especially to squirrels (Allen 1987).

Sometimes animals have very specific habitat needs relative to the overall forest community. For example, Wharton et al. (1982) listed numerous

vertebrate and invertebrate species found in the different zones of the bottomland hardwood community that are closely associated with the litter layer, either using it for food or for cover. Litter provides ideal habitat for small, secretive animals such as salamanders (Johnson 1987) and has a distinctive invertebrate fauna (Wharton et al. 1982) that is vital to some of the more visible members of the community. For example, wood ducks are known to forage extensively on macroinvertebrates found in the floodplain prior to egg laying. Similarly, mallards heavily utilize the abundant litter invertebrate populations associated with flooded bottomland forests during winter (Batema, Henderson, and Fredrickson 1985). Generally, the higher portions of the floodplain (Zones IV and V) have the highest amounts of litter (Wharton et al. 1982).

Logs and other woody debris provide cover and a moist environment for a myriad of species including invertebrates, small mammals, reptiles, and amphibians (Hunter 1990). Animals found in forested wetlands use logs as resting sites, feeding platforms, and as sources of food (Harmon, Franklin, and Swanson 1986). Logs provide cover, runways, and feeding sites for small mammals (Loeb 1993). It was noted that at least 55 of 81 species of mammals in the Southeast use downed woody debris and that it may be a critical habitat feature for some. Reptiles and amphibians likewise use logs and other coarse woody debris extensively. Whiles and Grubaugh (1993) summarized the literature on the use of woody debris by herptofauna and listed reproduction, feeding, thermoregulation, and protection from desiccation as important functions associated with coarse woody debris. Some specific examples of use of logs by species in riverine wetlands include nesting sites for marbled salamanders (*Ambystoma opaceum*) and basking sites for watersnakes in the genus *Nerodia*. To further illustrate how significant some of these small-scale features may be, Elton (1968) estimated that in England nearly 1,000 animal species rely on dead and dying wood for food or cover. Such a comprehensive listing is specifically lacking for southern riverine wetlands; however, Wharton et al. (1982) listed numerous species from various taxonomic groups that are associated with litter, logs, and crayfish burrows in bottomland hardwood forests.

Standing dead trees are one of the most important of the special habitat features used by many species. Snags are used by numerous birds, and several are dependent on them for their existence (Scott et al. 1977). Stauffer and Best (1980) found that most cavity-nesting birds, particularly the primary cavity nesters such as woodpeckers, preferred snags over live trees. In southern riverine forests, some of the avian species using snags (in addition to the woodpeckers) include the wood duck, Carolina chickadee (*Parus carolinensis*), and prothonotary warbler (*Pronotaria citrea*). Mammals found in forested wetlands that are dependent on snags to an extent include the big brown bat (*Eptesicus fuscus*), gray squirrel, and raccoon (*Procyon lotor*) (Howard and Allen 1989). Hunter (1990) stated that although birds dominate the list of cavity users, most species of forest-dwelling mammals, reptiles, and amphibians, along with numerous invertebrates, seek shelter in cavities, at least occasionally. The type and abundance of snags needed vary among species. For example, woodpeckers can excavate cavities in hard snags while chickadees and

nuthatches (*Sitta* spp.) can do so only in snags in which the wood is very soft (Hunter 1990). Thus, having a forest with snags in several different stages of decay is desirable for supporting all potential users.

Site-specific topography is one of the most important physical factors affecting use by many wildlife species. For example, depressions on a floodplain pond water, sometimes for relatively long periods following rainfall or overflow events. These ponded areas provide excellent breeding habitat for a variety of semiaquatic organisms such as salamanders and frogs (Wharton et al. 1982, Johnson 1987). Breeding sites without predatory fish populations are very important for some species such as the marbled and mole salamanders (*Ambystoma opacum* and *A. talpoideum*), gray treefrog (*Hyla versicolor*), and woodfrog (*Rana sylvatica*) (Johnson 1987). Also important are sites that retain water for a period sufficient for eggs to hatch or larvae to develop, generally 2-3 months for anurans (Duellman and Trueb 1986), thus shallow depressions such as those characterized by *Quercus lyrata* and *Carya aquatica* may be especially important. Distribution of frogs and salamanders varies across the floodplain and is described by Wharton et al. (1982).

Slightly higher areas which do not flood are important to ground-dwelling species that cannot tolerate prolonged inundation. Wharton et al. (1982) stated that old levee ridges are extremely important in the life of many floodplain species, because they provide winter hibernacula and refuge areas during periods of high water. Similarly, Tinkle (1959) found that levees were used extensively by many reptiles and amphibians as egg-laying areas. Keiser (1976) noted that the marbled salamander (*Ambystoma opacum*) does not occur in areas that flood for long durations. Presumably, small mammals that utilize the floodplains of southern forested wetlands (e.g., the deer mouse (*Peromyscus maniculatus*), golden mouse (*Ochrotomys nuttalli*), short-tailed shrew (*Blarina brevicauda*), and southeastern shrew (*Sorex longirostris*)) (Wharton et al. 1982) also benefit from the presence of higher areas in the floodplain. Wharton et al. (1982) noted that the latter two species retreat to higher ground during periods of inundation. Other mammals that probably use the higher ridges during flood events include the swamp rabbit (*Sylvilagus aquaticus*), mink (*Mustella vison*), and raccoon.

It is assumed that the more variable the surface of the wetland is, the greater the variety of wildlife species that will utilize it. Topographic complexity results in plant community complexity, and this, along with ponded depressions of varying sizes and depths, greatly enhances the ability of the wetland to support the differing needs of a high diversity of aquatic, semiaquatic, and terrestrial wildlife species.

Landscape-level features such as forest patch size, shape, connectivity, and surrounding land use also are important attributes that affect the wildlife community (Hunter 1990; Morrison, Marcot, and Mannan 1992). Many of the concepts regarding these landscape features originated with MacArthur and Wilson's (1967) theory of island biogeography which states that immigration and extinction rates that control population size are themselves influenced by island size and spatial considerations. In general, larger islands that are near a

source of colonists support larger and more stable populations. It is believed that reduction and fragmentation of forest habitat, coupled with changes in the remaining habitat, resulted in the loss of the ivory-billed woodpecker (*Campephilus principalis*), Bachman's warbler (*Vermivora bachmanii*), and the red wolf (*Canis rufus*) and severe declines in the black bear (*Ursus americanus*) and Florida panther (*Puma concolor*).

Recent studies that have investigated whether this size area relationship is true in forested habitats (some have been forested wetlands) relative to bird populations have yielded mixed results. For example, Stauffer and Best (1980); Howe (1984); Askins, Philbrick, and Sugeno (1987); Keller, Robbins, and Hatfield (1993); and Kilgo et al. (1997) found that bird species richness increases with forest area (generally through the addition of edge species). Other studies have concluded that there is no relationship or even a negative relationship between bird species richness and area (Blake and Karr 1984; Lynch and Whigham 1984; Sallabanks, Walters, and Collazo 1998).

While the effects of patch size alone on overall bird species richness need additional clarification, the negative effects of forest fragmentation on some species of birds have been well documented (Finch 1991). These species, referred to as "forest interior" species, apparently respond negatively to unfavorable environmental conditions or biotic interactions in fragmented forests (Ambuel and Temple 1983). Nests near forest edges have been found to experience higher rates of nest predation (Wilcove 1985, Yahner and Scott 1988) and parasitism by brown-headed cow-birds (Brittingham and Temple 1983). Thus, as forests become fragmented into smaller and smaller blocks, the amount of "edge" habitat relative to the amount of "interior" habitat increases, leading to declines of species sensitive to such changes. At what point fragmentation effects begin to be realized has yet to be defined. Some studies suggest that most predation and brood parasitism occur within about 100 m of the forest edge (Temple 1986), although recent work in a forested riparian corridor in Arkansas showed that avian parasites and predators penetrate deeply into even large forest tracts (Wakeley and Roberts 1996). A distance of 300 m is probably more appropriate than 100 m as a buffer.

The size area needed to accommodate all the species typically associated with unfragmented blocks of forested wetlands in the region can only be approximated. Except for a few wide-ranging carnivores, most of the concern about fragmentation effects have involved birds; thus, they are the best group to serve as a guide for developing standards for the entire wetland faunal community. The number of breeding bird species detected by Wakeley and Roberts (1996) in an intact riparian corridor (N = 43) was similar to that found by Hamel (1989) in the Congaree Swamp , South Carolina (N = 41 in old growth bottomland hardwoods and 47 in selectively harvested bottomland hardwoods). These richness values probably approach the maximum that can be expected in large, relatively unfragmented southern forested wetlands. Nineteen species considered to be area sensitive (Temple 1986; Robbins, Dawson, and Dowell 1989) were present in the Arkansas study area, although two species expected to be present, the cerulean warbler (*Dendroica cerulea*) and Swainson's warbler

(*Limnothlypis swainsoni*), were absent. This suggests that the 2-3 km width of the forested corridor, in conjunction with more than twice that distance linearly, while sufficient to support most area-sensitive species, still was too small for some with larger area requirements.

When the maintenance of breeding populations is considered, in addition to simply supporting or not supporting individuals of a species, the size of the area needed may be magnified significantly. For example, Mueller, Loesch, and Twedt (1995) identified three groups of birds that breed in the Mississippi Alluvial Valley with (presumably) similar needs relative to patch size. They suggested that to sustain source breeding populations of individual species within the 3 groups, that 44 patches of 4,000 - 8,000 ha, 18 patches of 8,000 - 40,000 ha, and 12 patches larger than 40,000 ha are needed. Species such as the Swainson's warbler are in the first group; more sensitive species such as the cerulean warbler are in the second group; and those with very large home ranges (e.g., raptors such as the red-shouldered hawk (*Buteo lineatus*)) are in the third group.

The land-use surrounding a tract of forest also has a major effect on avian populations. Recent studies (Thompson et al. 1992; Welsh and Healy 1993; Sallabanks, Walters, and Collazo 1998; Robinson et al. 1995) suggest that bird populations respond to fragmentation differently in forest-dominated landscapes than in those in which the bulk of the forests have been permanently lost to agriculture or urbanization. Generally, cowbird (*Molothrus ater*) populations are higher in fragmented landscapes where there is a mixture of feeding habitats (agricultural and suburban lands) and breeding habitats (forests and grasslands) (Robinson et al. 1993, 1995). In such areas, even large blocks of habitat may lack the secure "interior" conditions needed by some species (Robinson et al. 1995). Formerly, cowbirds were thought to penetrate only relatively short distances (e.g., 300 m) (Temple and Cary 1988) into forests, but recent studies (Wakeley and Roberts 1996, Thompson et al. 1998) found cowbirds much farther from the nearest edge. Both studies were conducted in areas in which the landscape matrix was agricultural. Robinson et al. (1995) reported that predation rates also were much higher in the most fragmented landscapes and suggested that landscapes that are largely forested may be necessary to provide colonists to maintain populations of some species in highly fragmented areas. Robinson (1996) suggested that the area within a 9.6-km radius of a study site (approximately 30,300 ha) was an appropriate estimator. Further, he noted that as the percentage of the landscape that is forested increases above 70 percent (approximately), the size of the forest blocks within that landscape becomes less significant to bird populations. Thus, in more open landscapes, block sizes need to be larger than in mostly forested ones.

In landscapes that are fragmented, corridors have been suggested as a means of ameliorating many of the anticipated negative effects of fragmentation (Harris 1985, Noss and Harris 1986). Intuitively, corridors should be beneficial to a range of species; however, Simberloff et al. (1992) argued that many of the proposed benefits of corridors (increased migration with a subsequent reduction in extinction) have never been substantiated. Part of the confusion surrounding

corridors is the scale at which they are viewed. Harris (1988) advocated an extensive network of corridors in Florida to connect national forests, refuges, and other large blocks of land. Some of these corridors would have to be >4 km wide. This concept is very different from connecting a small isolated block of habitat to another block by means of a narrow (e.g.,<100 m) strip of habitat. Hunter (1990) concluded that the value of corridors was species-specific, but for some animals, corridors probably would be beneficial.

In bottomland forest communities, probably the most significant habitat connection to many species is between the wetland and a block of similar habitat in the adjacent uplands. Such a connection is invaluable for allowing terrestrial species, especially, to move from the floodplain during periods of very high water (Wharton et al. 1982). In general, connections between different wetland types, and between uplands and wetlands, help maintain higher animal and plant diversity across the landscape than if habitats were more isolated from one another (Sedell et al. 1990).

Although it is impossible to describe the optimum size of forested riverine wetlands, relative to fish and wildlife habitat, or at what point landscape factors begin to degrade habitat quality, it is possible to generalize about these concepts. It can be assumed that large tracts with a high ratio of interior to edge habitat are preferred over smaller ones with little interior habitat. Also, it can be assumed that other types of "natural" habitat, including upland areas, are important, especially to wildlife, and the closer together these areas are, the greater the diversity of wildlife utilizing them will be. Generally, the continuity of vegetation, connectivity of specific vegetation types, the presence and scope of corridors between upland/wetland habitats, and corridors among wetlands all have direct bearing on the movement and behavior of animals that use wetlands.

Description of site scale model variables

This function is community based and evaluates wildlife habitat by assessing site-specific and landscape level variables which focus on the avifauna. The model contains 11 variables representing 3 major components of wildlife habitat (hydrology, plant community, and landscape) which are related to the richness and abundance of birds in the riverine low gradient subclass. The assumption in this model is that if habitat requirements for birds are met, then a broad range of other wildlife species habitat requirements will also be met. For instance, downed logs and litter are required for towhees, wrens, and Tennessee warblers. These habitat components are also utilized by small mammals and herptofauna for cover and feeding. The following variables are grouped by the three major habitat components listed above for the purpose of organization and clarity.

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flooding of the proper frequency, depth, and duration maintains a characteristic plant community which in turn influences fish and wildlife richness and diversity.

Certain fish species depend on overbank events during the appropriate season to allow access to the floodplain for foraging and spawning. Frequent flooding, even for short durations, keeps soil and litter moist and provides pools of surface water in depressions that serve as important sources of water for wildlife and are critical for reproduction in some invertebrates and amphibians.

A fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999) is used to quantify this variable (this and other methods to quantify this variable are described in Appendix C). Overbank flood frequency is a function of discharge and channel capacity (cross-sectional area). The procedure for measuring it is described on page 33.

In western Tennessee reference standard wetlands, channel cross-sectional area is described by the regression equation $16.4 \times DA^{0.57}$. Based on the fluvial geomorphic regional curve of channel cross-sectional area (Smith and Turrini-Smith 1999), sites adjacent to rivers with areas within a factor of 2 are assigned a subindex of 1.0 (Figure 41). Sites adjacent to channels with a departure from the curve by a factor of 2 to 4 are assigned a subindex of 0.5. Sites with a departure of greater than 4 are assigned a subindex of 0.1. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the cross-sectional area of the channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur with less frequency, the habitat is expected to be different than that characteristic of reference standard sites. The rationale at which the subindex is scaled is based on data from the USGS gage at Bolivar for the growing season over a 67-year period, and the magnitude of scatter within the data is used to develop the regional curve (Appendix C). Model validation will help refine the actual nature of this relationship.

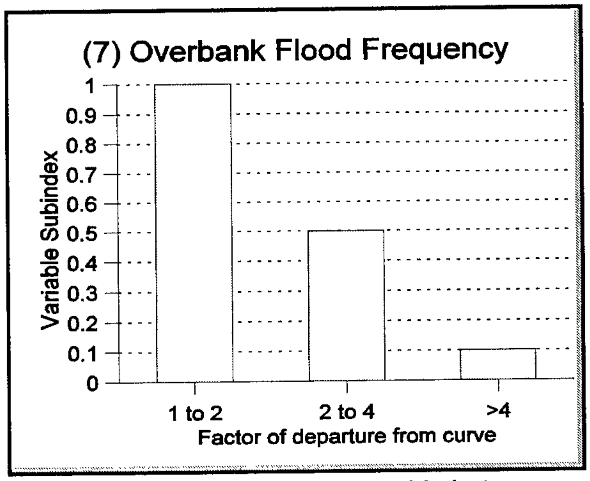

Figure 41. Function 8: Relationship between channel cross-sectional area and functional capacity

Macrotopographic features (V_{MACRO}). This variable represents the occurrence of macrotopographic features in the riverine wetland. Macrotopographic features are defined as floodplain topographic features large enough to be detected on 1:2400 scale aerial photographs, greater than 1 m in depth, and capable of holding water for extended periods of time. Normally these features lack outlets and thus trap surface water on a semipermanent basis. Abandoned channels are typical macrotopographic features in western Tennessee riverine wetlands. In the context of this function, the surface water impounded by macrotopographic features provides essential habitat to a variety of avifaunal species when floodwater recedes.

Macrotopographic relief is a large-scale feature of most floodplains. As such, the area in which this variable is assessed must be large enough to represent the floodplain. Therefore, 1 km^2 was chosen as the appropriate scale of measure. If the area being assessed is greater than 1 km^2, the percentage of the area that consists of macrotopographic features is used to quantify this variable. Measure it with the procedure outlined under Alternative 1 if the area being assessed is greater than 1 km^2 or Alternative 2 if the area is less than 1 km^2.

(1) Alternative 1: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in the assessment area.

(2) Alternative 2: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in a 1-km^2 area around the assessment area. For instance, a 1-km^2 template can be placed on a map or aerial photograph of appropriate scale, and the percentage of that area covered by macrotopographic features can be estimated.

(3) Report the percentage of the area being assessed that is covered with macrotopographic features.

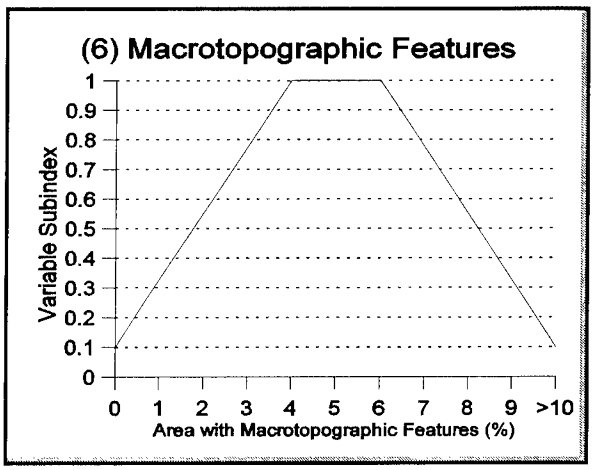

Figure 42. Function 8: Relationship between macrotopographic features and functional capacity

In western Tennessee reference wetlands, macrotopographic features covered between 0 and 10 percent of the area being assessed (Appendix D). Based on the range of values from reference standard wetlands, a variable subindex of 1.0 is assigned when the percentage of the area being assessed with macrotopographic features is between 4 and 6 percent (Figure 42). As the percent of area with macrotopographic features decreases, the subindex decreases linearly down to a 0 when 0 percent of the area is covered with macrotopographic features. This is based on the assumption that as the extent of ponding decreases, so does available habitat. As the percent of area with macrotopographic features exceeds 6 percent, a linearly decreasing subindex down to 0.1 is assigned at $\geq$10 percent macrotopographic features. This is based on the assumption that as macrotopographic features exceed 10 percent, wildlife habitat is affected adversely because much of the terrestrial topographic diversity is replaced with open water.

Plant species composition (V_{COMP}). Plant species composition represents the diversity of vegetation in riverine wetlands. In general, a healthy, mature

forest with a characteristic composition of plant species in each stratum will support higher species diversity than younger stands due to the greater overall complexity. Plant species composition is important to avifauna because of food sources produced (i.e., hard mast, soft mast, fruits, and seeds), timing of food production (spring seeds vs. autumn production of acorns), and cover and nesting sites provided. Ideally, determining plant species diversity requires an intensive survey of all herbaceous and woody species in all vegetation strata. Unfortunately, the time and taxonomic expertise required to accomplish this is not available in the context of rapid assessment. Thus, the focus here is on the dominant species in each vegetation stratum.

Percent concurrence with the dominant species in all vegetation strata is used to quantify this variable. The procedure for measuring this variable is described on page 85.

In the flat zones of western Tennessee reference wetlands, percent concurrence of dominant species ranged from 0 to 100 percent (Appendix D). Based on the data from reference standard sites supporting mature and fully stocked forests, a variable subindex of 1.0 is assigned when dominant species concurrence is 100 percent (Figure 43). As percent concurrence decreases, a linearly decreasing subindex down to zero is assigned based on the assumption that the relationship between plant species composition and the capacity of the riverine wetland to support a diverse avifaunal community is linear. This assumption can be validated using the independent, quantitative measures of function identified above.

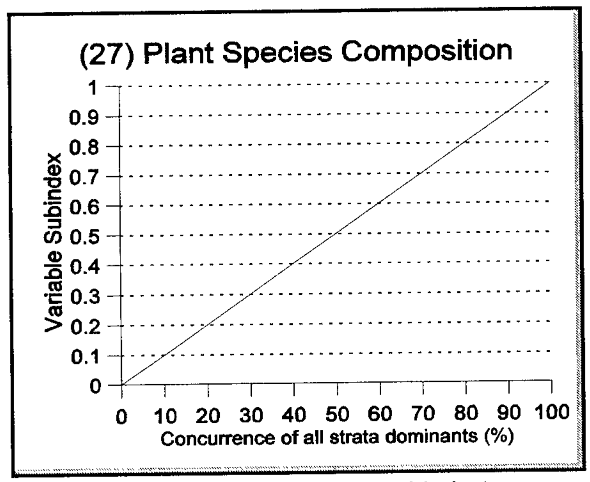

Figure 43. Function 8: Relationship between percent concurrence of strata dominants and functional capacity

Tree biomass (V_{TBA}). This variable represents the total mass of organic material per unit area in the tree stratum. Trees are defined as woody stems ≥6 m in height and ≥10 cm in diameter at breast height (dbh), which is 1.4 m above the ground (Bonham 1989). Tree biomass is correlated with forest maturity (Brower and Zar 1984) and, in the context of this function, serves as an indicator of plant community structure.

Tree basal area is used to quantify this variable. The procedure for measuring this variable is described on page 52.

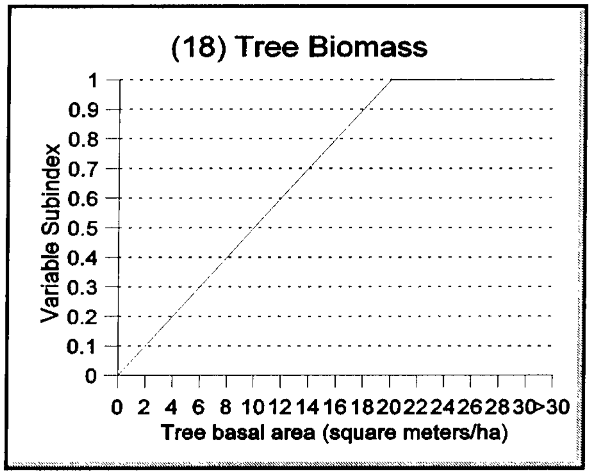

Figure 44. Function 8: Relationship between tree basal area and functional capacity

In western Tennessee reference wetlands, tree basal area ranged from 0 to 64 m^2/ha (Appendix D). Based on the data from reference standard sites supporting mature and fully stocked forests, a variable subindex of 1.0 is assigned when tree basal area is $\geq$20 m^2/ha (Figure 44). At reference sites in the middle to early stages of succession, or cleared for agriculture, tree basal area decreases, and a linearly decreasing subindex down to zero at zero tree basal is assigned. This is based on the assumption that the relationship between tree basal area and the capacity of the riverine wetland to provide habitat is linear. This assumption could be validated using the data from a variety of low gradient, riverine wetlands in the Southeast, summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997), or the independent, quantitative measures of function identified above.

Tree Density (V_{TDEN}). This variable represents the number of trees per unit area in riverine wetlands. Trees are defined as woody stems $\geq$6 m in height and $\geq$10 cm dbh. In most forested systems, tree stem density and basal area increase rapidly during the early successional phase. Thereafter, tree density decreases and the rate at which basal area increases diminishes as the forest reaches mature steady-state conditions (Spurr and Barnes 1981). In the context of this function, tree density serves as an indicator of plant community structure.

The density of tree stems per hectare is the measure of this variable. Measure it with the following procedure.

(1) Count the number of tree stems in a circular 0.04-ha plot (radius = 11.3 m).

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocols, provides guidance for determining the number and layout of sampling units.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 20 stems, then 20 $\times$ 25 = 500 stems/ha.

(4) Report tree density in stems/hectare.

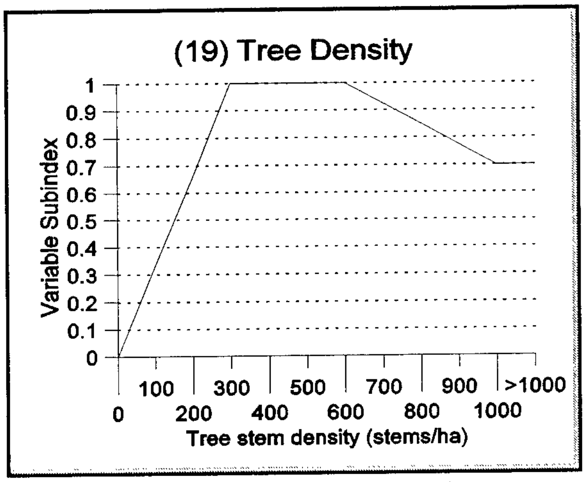

Figure 45. Function 8: Relationship between tree density and functional capacity

In the flats zone of western Tennessee reference wetlands, tree stem density ranged from 0 to 1,350 stems/ha (Appendix D). Based on the range of values at reference standard wetlands sites, a variable subindex of 1.0 is assigned when tree stem densities are between 300 and 600 stems/ha (Figure 45). At sites that have been cleared for agricultural or other activities, where tree stem density is zero, a subindex of zero is assigned. As tree stem densities gradually increase during the early and midstages of succession, a linearly increasing subindex is assigned up to 1.0 at 300 stems/ha. As secondary succession continues, stem densities often exceed 1,000 stems/ha, a linearly decreasing subindex down to 0.7 at ≥1,000 stems/ha is assigned. This is based on the assumption that the relationship between tree stem density and the capacity of the riverine wetland to provide wildlife habitat (particularly avifauna) is linear. This assumption could be validated by analyzing the relationship between tree stem density and the capacity to provide wildlife habitat using the data from a variety of low gradient, riverine wetlands in the Southeast, summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997), or the independent, quantitative measures of function identified above.

Log biomass (V_{LOG}). This variable represents the total mass of organic matter contained in logs on or near the surface of the ground. Logs are defined as down and dead woody stems >7.5 cm (3.0 in.) in diameter that are no longer attached to living plants. In the context of this function, log biomass represents habitat for organisms that utilize logs for refugia, feeding, or breeding.

Volume of woody debris per hectare (>7.5 cm in diameter) is used to quantify this variable. The procedure for measuring this variable is described on page 58.

In western Tennessee reference wetlands, the log volume ranged from 0 to 740 m^3/ha (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when log volumes are between 10 and 20 m^3/ha (Figure 46). Below 10 m^3/ha, the subindex decreases linearly to 0 at a log volume of 0 m^3/ha. This range of values included

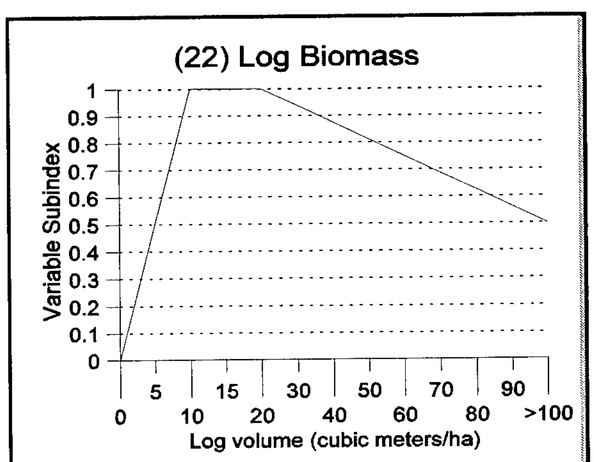

Figure 46. Function 8: Relationship between log volume and functional capacity

reference sites that had been converted to agriculture and had little or no woody debris and sites in early to middle stages of succession with a log volume <10 m^3/ha. The decrease in the variable subindex is based on the assumption that lower volumes of woody debris indicate an inadequate supply of the types of habitat provided by logs. Above 20 m^3/ha the subindex also decreases linearly to 0.5 at 100 m^3/ha. This is based on the assumption that higher log volumes begin to adversely affect the other habitat components in the riverine wetland, but logs are still utilized by wildlife species. This situation occurs after logging, timber kill from excessive ponding or sedimentation, or catastrophic wind damage.

Snag density (V_{SNAG}). This variable represents the number of snags in riverine wetlands. Snags are defined as standing dead woody stems ≥6 m in height and ≥10 cm dbh. In the context of this function, the snag density relates to the suitability of a site as wildlife habitat due to the large number of species that forage on and nest and den in snags.

The density of snag stems per hectare is used to quantify this variable. Measure it with the following procedure.

(1) Count the number of snag stems in a circular 0.04-ha plot.

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 2 stems, then $2 \times 25 = 50$ stems/ha.

(4) Report the density of snags in stems/hectare.

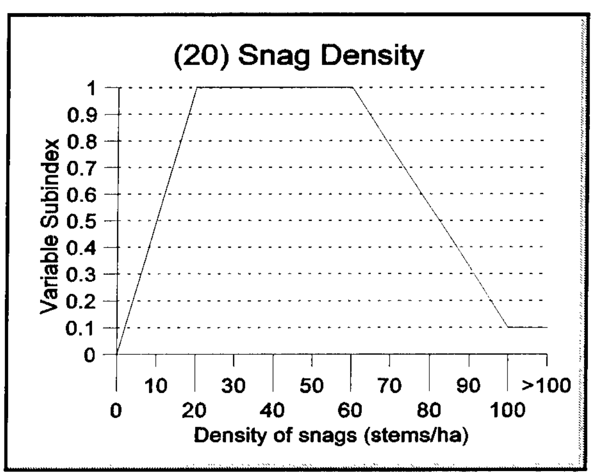

Figure 47. Function 8: Relationship between snag density and functional capacity

In western Tennessee reference wetlands, snag density typically ranged from 0 to 325 stems/ha. (Appendix D). Based on the range of values at reference standard wetlands, a variable subindex of 1.0 is assigned when snag densities are between 20 and 60 stems/ha (Figure 47). Below 20 snags/ha, the subindex decreases linearly to 0 at a snag density of 0 stems/ha. Above 60 snags/ha the subindex decreases linearly to 0.1 at a snag density of ≥100 stems/ha. This is based on the assumption that fewer snags reflect a decrease in the availability of

snag habitat and a higher number of snags begin to adversely affect the other habitat components in the riverine wetland.

"O" horizon biomass (V_{OHOR}). This variable represents the total mass of organic matter in the "O" horizon. The "O" horizon is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks or twigs < 0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA SCS 1993). The "O" horizon is synonymous with the term detritus or litter layer used by other disciplines. In the context of this function, this variable represents the importance of leaves and small woody debris for the production of many wetland forest invertebrates upon which many avifaunal species feed.

Percent cover of the "O" soil horizon is used to quantify this variable. The procedure for measuring this variable is described on page 56.

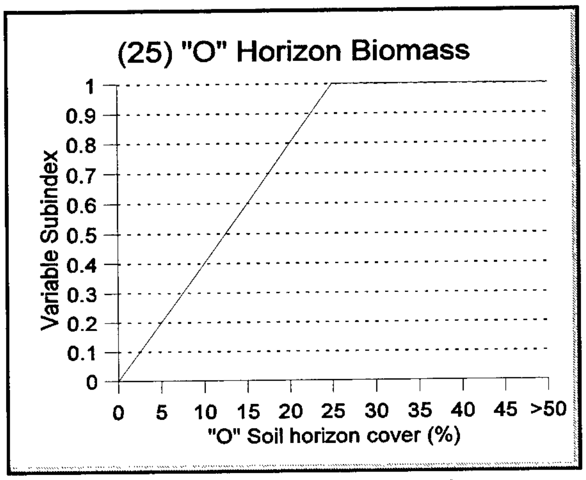

Figure 48. Function 8: Relationship between "O" soil horizon and functional capacity

In the flat zones of western Tennessee reference wetlands, percent "O" horizon cover ranged from 0 to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the "O" soil horizon cover is >25 percent (Figure 48). As "O" horizon cover decreases, a linearly decreasing subindex down to 0 at 0 percent cover is assigned. The rate at which the subindex decreases, and the selection of 0 as the subindex endpoint at 0 percent cover, is based on the assumption that the relationship between "O" soil horizon cover and opportunities for ground feeding species is linear. When "O" soil horizon drops to 0 percent, no habitat for litter dwelling invertebrate species is available, thus feeding opportunities for ground feeding birds have essentially ceased. These assumptions could be validated using the independent, quantitative measures of function defined above.

Description of landscape scale model variables

This section describes model variables used to assess the capacity of the forested wetland tract to support wildlife species in a landscape context. The size of the tract is perhaps the most important determinant of forest species richness, with larger tracts supporting more species (i.e., the species-area concept). However, size alone is not the only factor affecting the suitability of a particular tract to support a bottomland hardwood wildlife community. Habitat fragmentation can modify the effective size of the forested wetland tract, which

affects the ability of the tract to contribute to the long-term wildlife richness (Schroeder, O'Neil, and Pullen in preparation; Schroeder 1996a,b). The assumptions incorporated into the following landscape variables are:

a. Large tracts with a high ratio of interior-to-edge habitat are preferred over smaller ones with little interior habitat

b. Other types of "natural" habitat, including upland areas, are important to wildlife, and, the closer together these areas are, the greater the diversity of wildlife utilizing them

c. The landscape for which these model variables were scaled (western Tennessee) is fragmented by agriculture. In largely unfragmented landscapes, these variables would have to be rescaled since faunal populations respond differently in these landscapes than in fragmented landscapes.

The following variables assess the ability of the wetland tract to support wildlife populations based not only on its inherent capability but on its position in the landscape.

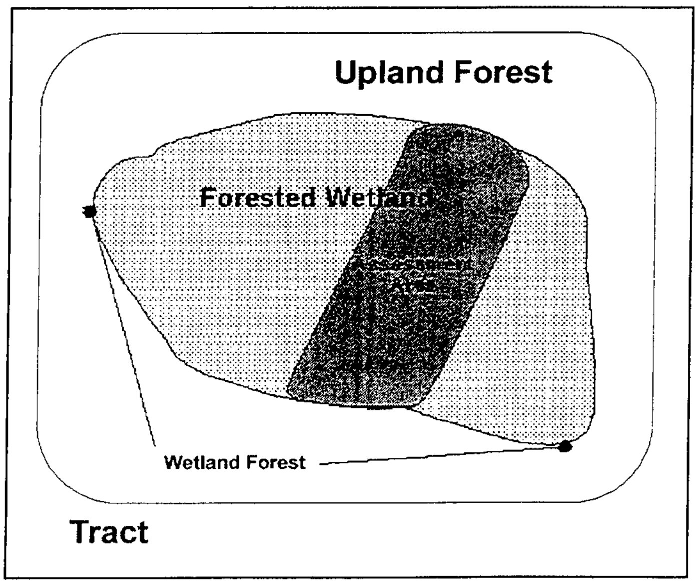

Figure 49. Function 8: Relationship of assessment area to the larger area of contiguous wetland of the same subclass for determining wetland tract

Forest tract area (V_{TRACT}). This variable is the area of low-gradient riverine wetland forest and upland forest that is contiguous and directly accessible to wildlife from the area being assessed (Figure 49). In the context of this function, this variable represents the fact that wildlife movement is not constrained by imaginary lines on a map such as project boundaries. Although species-dependent wildlife movement is more likely to be constrained by factors such as the size of home range, and ecologically meaningful boundaries are more likely to be distinguished by changes in land use, habitat type, or structures such as roads.

The area of wetland and upland forest that is contiguous with the area being assessed is used to quantify this variable. Measure it with the following procedure.

(1) Determine the size of the area of wetland and upland forest that is contiguous with the assessment area using field reconnaissance,

topographic maps, National Wetland Inventory maps (NWI), or aerial photography.

(2) Record the size of the area in hectares.

In western Tennessee reference wetlands, forest tract size ranged from 0 to 21,412 ha (Appendix D). This range assumes that two-lane state highways and powerline corridors do not represent significant barriers to most wildlife. Larger roads and discontinuities were treated as tract boundaries. Based on data from reference standard sites in western Tennessee and avifauna data from forested wetland tracts in the mid-Atlantic region (Schroeder 1996b; Robbins, Dawson, and Dowell 1989), a variable subindex of 1.0 is assigned when forest tract size is >3,000 ha since this is the minimum needed to retain all breeding forest birds (Figure 50). Tracts between 601 and 3,000 ha (1,500-7,500 acres) are assigned a subindex of 0.7 since 12 forest interior bird species occur at 100 percent frequency in tracts as small as 600 ha (1,500 acres) (Blake and Karr 1984). Forested tracts between 101 and 600 ha (250-1,500 acres) are assigned a subindex of 0.5 since, at 100 ha (250 acres), 87 percent frequency of occurrence of interior bird species has been documented (Temple 1986). Forest tracts between 16 and 100 ha (40-250 acres) receive a model variable subindex of 0.3 since tracts greater than 16 ha regularly contain interior bird species (Blake and Karr 1984). Forest tracts between 1 and 16 ha (2.5-40 acres) receive a model variable subindex of 0.0 since they contain virtually no interior birds (Blake and Karr 1984).

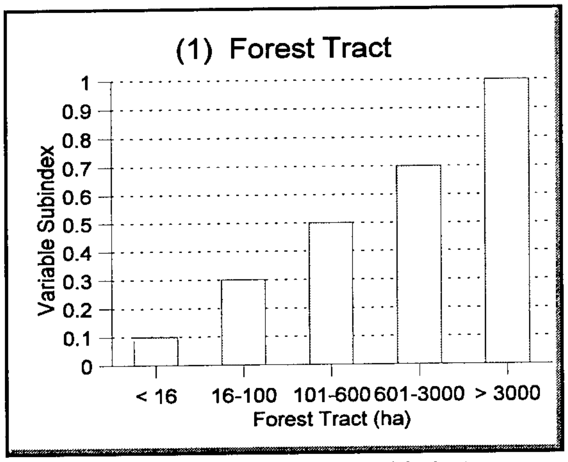

Figure 50. Function 8: Relationship between wetland tract size and functional capacity

Interior core area (V_{CORE}). This variable represents the interior portion of the forest tract with at least a 300-m (990-ft) buffer separating it from adjacent nonforested habitat (Figure 51). Interior core area is dictated by both the size and shape of the wetland. Large tracts often have large interior core areas, but not always. For example, a large tract

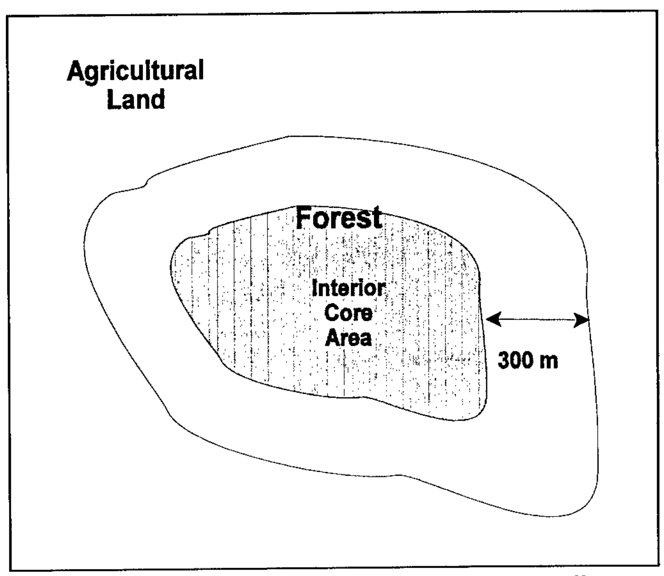

Figure 51. Function 8: Interior core area and buffer zone

that is circular in shape will have a much larger interior core area than a linearly shaped tract of the same size. In the context of this function, this variable represents the availability of forested interior core areas that benefit forest interior bird species which are adversely affected by forest fragmentation and the creation of edge habitat.

The percentage of the forest tract inside a buffer zone >300 m separating it from nonforested habitat is used to quantify this variable. Measure it with the following procedure.

(1) Determine the area of the forest tract with a buffer of at least 300 m using field reconnaissance, topographic maps, NWI maps, aerial photography, or other sources.

(2) Divide the area within the buffer by the total size of the forest tract and multiply by 100. The result is the percentage of the forest tract within a buffer zone >300 m.

(3) Report the size of the area within a 300-m buffer as a percentage of total tract area.

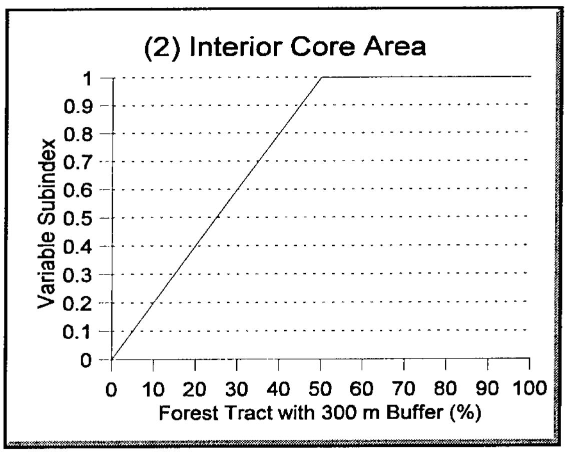

Figure 52. Function 8: Relationship between interior core area and functional capacity

In western Tennessee reference wetlands, the percentage of the forest tract within a buffer of at least 300 m ranged from 0 to 84 percent (Appendix D). Based on the range of values from reference standard wetlands, a variable subindex of 1.0 is assigned when 50 percent or more of the forest tract is inside a buffer of at least 300 m (Figure 52). As the percentage of the tract within a 300-m buffer decreases, a linearly decreasing subindex is assigned down to 0 at 0 percent. This is based on the assumption that, as the interior core area decreases, the suitability of the area for species requiring isolation from predators and nest parasites that frequent edges also decreases.

Habitat connections ($V_{CONNECT}$). This variable is defined as the percentage of the perimeter of a wetland that is connected to other types of wetlands, upland forests, or other suitable wildlife habitats (Figure 53). Suitable habitats are other forested, naturally vegetated, or wetland areas. Agricultural fields, recent clear cuts, recent mined areas, or developed areas are not considered suitable habitat. An adjacent habitat is considered connected if it is within 0.5 km of the perimeter of the wetland. In the context of this function, this variable represents the need many species of wildlife have for other types of habitat to carry out their daily activities such as feeding or resting, or to complete a particular phase

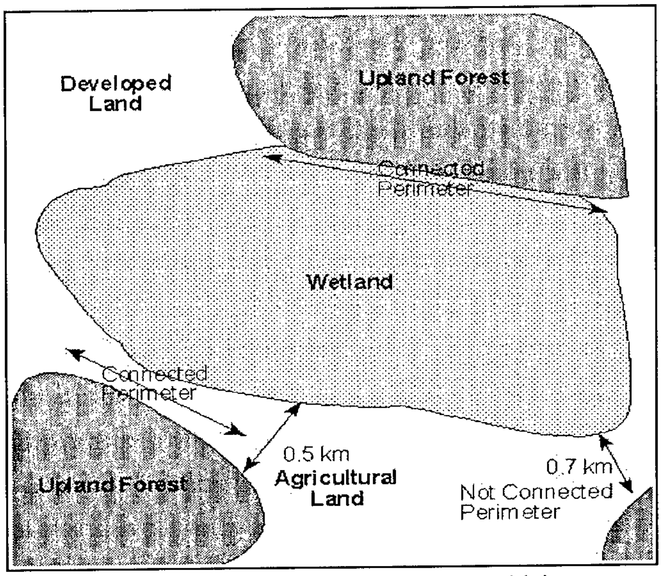

Figure 53. Function 8: Adjacent habitats which are considered connected and not connected for determining $V_{CONNECT}$

of their life cycle. Birds and most of the large terrestrial vertebrates are capable of moving substantial distances (i.e., several kilometers) to disjunct patches. Smaller organisms with poor dispersal ability are the focus of this variable. Migration distances for most anurans (frogs, toads, etc.) seldom exceed 1,500 m and most species of salamanders move <500 m (Sinsch 1990). The most restrictive distance, 0.5 km, was chosen as the threshold between connected and disconnected habitats.

The percentage of the perimeter of the wetland tract that is "connected" is used to quantify this variable. Measure it using the following procedure.

(1) Determine the total length of the wetland tract perimeter using field reconnaissance, topographic maps, or aerial photography.

(2) Determine the length of the wetland perimeter that is "connected" to suitable habitats such as other types of wetlands, upland forests, or other wildlife habitats.

(3) Divide the length of "connected" wetland perimeter by the total length of the wetland perimeter.

(4) Convert to a percentage of the perimeter by multiplying by 100.

(5) Report the percentage of the perimeter of the wetland tract that is connected.

In western Tennessee reference wetlands, the ratio of connection to total perimeter length ranged from 0 to 22 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when more than 10 percent of the wetland tract perimeter is connected (Figure 54). As the percentage of wetland tract perimeter

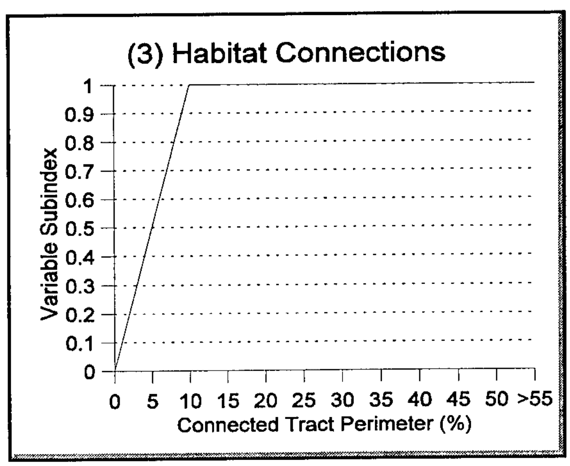

Figure 54. Function 8: Relationship between tract perimeter connections and functional capacity

decreases, a linearly decreasing subindex is assigned down to 0 at 0 percent connected wetland tract perimeter. This is based on the assumption that, as connections to other suitable habitats decrease, so does the suitability of the wetland tract as habitat for wide ranging species or for those that move to upland habitat during periods of prolonged inundation.

Functional capacity index

The aggregation equation for deriving the FCI for the wildlife habitat function is as follows:

$$FCI = \left[\frac{\left(\frac{F_{FREQ} + V_{MACRO}}{2} \right) + \left(\frac{V_{TRACT} + V_{CONNECT} + V_{CORE}}{3} \right)}{2} \times \frac{V_{COMP} + V_{TBA} + V_{TDEN} + \left(\frac{V_{LOG} + V_{SNAG} + V_{OHOR}}{3} \right)}{4} \right]^{1/2} \tag{16}$$

This model is assumed to reflect composition and abundance of avian and other wildlife species in the riverine low gradient subclass. If all these components are similar to reference standard condition (i.e., a large, diverse, unfragmented, mature forested system which floods regularly), there is a high probability that the full complement of birds (and, by inference, other groups such as small and large mammals, reptiles, amphibians, fish, and invertebrates) typically associated with forested wetlands will be present. The variables have been grouped by the three major components of hydrology, biotic community, and landscape. It should be noted that the emphasis is on onsite conditions. Even in largely fragmented landscapes, if reference standard conditions exist onsite, the majority of fish and wildlife species will be present; however, the site probably would not support some (10-15) area-sensitive species of interior birds and large carnivores.

Frequency of overbank flow (V_{FREQ}) is used in this function because a site must flood regularly for species that require water or moist conditions (amphibians and litter invertebrates) to use the wetland. V_{FREQ} also is used to assess whether or not fish and other aquatic organisms can obtain regular access to the floodplain. The assumption is that annual flooding provides optimal access by aquatic organisms. V_{MACRO} is an indicator of the surface complexity of the wetland for fish and other aquatic organisms. The presence of these features is indicative of a diverse ecosystem and increases the probability of the site supporting a diversity of fish and wildlife. V_{MACRO} also represents the presence of permanent or semipermanent water in the wetland. V_{MACRO} is considered independent of V_{FREQ} since ponding of surface water can occur from water sources besides overbank flow and ponding is not always a consequence of flooding. Therefore, ponded areas may occur within the wetland in the absence

of flooding, and, conversely, flooding may occur with no resulting ponding. Thus, V_{MACRO} and V_{FREQ} are averaged.

The habitat structure has both living and detrital components. The living portion is represented by the variables V_{COMP}, a reflection of the similarity of the community to reference standard conditions, and V_{TDEN} and V_{TBA} , measures of stand maturity, which provide an indication of seral stage. It is assumed that a mature stand composed of species reflective of late seral stages (generally oak-dominated) represents a diverse, stable community with diverse, stable wildlife populations. V_{TDEN} and V_{TBA} also provide an indicator of forest stand structure. The assumption is that, as the stand matures, structure will become more diverse and provide more wildlife habitat. Log volume (V_{LOG}) represents the amount of cover, foraging, and reproductive sites available for a variety of wildlife species. Leaf litter (V_{OHOR}) represents habitat for invertebrates and selected small mammals. Snags (V_{SNAG}) are an important structural component of habitat that serve as perches for birds, provide cavities and dens for numerous species, and provide foraging sites for species that utilize invertebrates. V_{LOG} , V_{OHOR} , and V_{SNAG} are considered independent of one another and are averaged to account for minor structural components of habitat.

The variables forest tract area (V_{TRACT}), interior core area (V_{CORE}), and connectedness to other habitats ($V_{CONNECT}$) reflect large scale attributes of the wetland and of the landscape in which the wetland is located. The assumption is that the more habitat there is available, the more wildlife utilization will occur. Essentially, these variables represent two components: size/shape and isolation of the wetland. V_{TRACT} and V_{CORE} represent the size and shape of the wetland and are considered together. $V_{CONNECT}$ represents the isolation of the wetland from adjacent suitable habitats.

In the first subpart of the aggregation equation, the variables representing hydrology are considered equally and are averaged. V_{FREQ} represents delivery of the water to the wetland surface and V_{MACRO} represents detention of the water. In the second subpart of the equation, the landscape level features (V_{TRACT} , $V_{CONNECT}$, *and* V_{CORE}) are considered independently and of equal weight and, consequently, are averaged. Landscape is considered to exert an equivalent influence on the function; therefore, it is averaged with hydrology. In the third subpart of the equation, V_{COMP} , V_{TBA} , V_{TDEN} , V_{LOG} , V_{OHOR} , and V_{SNAG} represent the plant community structure (both living and dead). The first three variables are considered of equal weight and, consequently, averaged. The latter three variables represent significant, but somewhat less important, structural conditions and are averaged separately. The onsite community represents the composition and structural components of habitat and are considered to exert a controlling influence on the function. Thus, the hydrology and landscape components are multiplied by the onsite community and averaged by a geometric mean. This arrangement of the aggregation equation reflects the assumption that site-specific aspects of habitat (i.e., biotic community/habitat structure) carry greater weight than landscape features. In other words, if the onsite community is degraded, the use of that wetland area by wildlife species will decrease even in a relatively unfragmented landscape with intact hydrology.

5 Assessment Protocol

Introduction

Previous sections of this Regional Guidebook provide background information on the HGM Approach and document the variables, measures, and models used to assess the functions of low gradient, riverine wetlands in western Tennessee. This chapter outlines a protocol for collecting and analyzing the data necessary to assess the functional capacity of a wetland in the context of a 404 permit review process or similar assessment scenario.

The typical assessment scenario is a comparison of preproject and postproject conditions in the wetland. In practical terms, this translates into an assessment of the functional capacity of the wetland assessment area (WAA) under both preproject and postproject conditions and the subsequent determination of how FCIs have changed as a result of the project . Data for the preproject assessment are collected under existing conditions at the project site, while data for the postproject assessment are normally based on the conditions that are expected to exist following proposed project impacts. A skeptical, conservative, and well-documented approach is required in defining postproject conditions. This recommendation is based on the often observed lack of similarity between predicted or "engineered" postproject conditions and actual postproject conditions.

This chapter discusses each of the tasks required to complete an assessment of low-gradient riverine wetlands in western Tennessee, including:

a. Define assessment objectives

b. Characterize the project area

c. Screen for red flags

d. Define the WAA

e. Collect field data

f. Analyze field data

g. Apply assessment results

Define Assessment Objectives

Begin the assessment process by unambiguously identifying the purpose for conducting the assessment. This can be as simple as stating "The purpose of this assessment is to determine how the proposed project will impact wetland functions." Other potential objectives could be: (a) compare several wetlands as part of an alternatives analysis, (b) identify specific actions that can be taken to minimize project impacts, (c) document baseline conditions at the wetland site, (d) determine mitigation requirements, (e) determine mitigation success, or (f) determine the effects of a wetland management technique. Frequently, there will be multiple purposes identified for conducting the assessment. Defining the purpose will facilitate communication and understanding between the people involved in conducting the assessment and will make the purpose clear to other interested parties. In addition, it will help to establish the approach that is taken. The specific approach will vary to some degree, depending on whether the project is a Section 404 permit review, an Advanced Identification (ADID), a Special Area Management Plan (SAMP), or some other scenario.

Characterize the Project Area

Characterizing the project area involves describing the project area in terms of climate, surficial geology, geomorphic setting, surface and groundwater hydrology, vegetation, soils, land use, proposed impacts, and any other characteristics and processes that have the potential to influence how wetlands at the project area perform functions. The characterization should be written and should be accompanied by maps and figures that show project area boundaries, jurisdictional wetlands, WAA, proposed impacts, roads, ditches, buildings, streams, soil types, plant communities, threatened or endangered species habitat, and other important features.

The following list identifies some information sources that will be useful in characterizing a project area.

a. Aerial photographs

b. Topographic and NWI maps

c. County Soil Survey

Screen for Red Flags

Red flags are features within, or in the vicinity of, the project area to which special recognition or protection has been assigned on the basis of objective

criteria (Table 15). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the wetlands or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of wetland function. The assessment of wetland functions may not be necessary if the project is unlikely to occur as a

Table 15
Red Flag Features and Respective Program/Agency Authority

Red Flag Features	Authority[1]
Native Lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA or RCRA	H
Areas protected by a Coastal Zone Management Plan	D
Areas providing Critical Habitat for Species of Special Concern	I
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or floodprone areas	J
Areas with structures/artifacts of historic or archeological significance	F
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	D
National wildlife refuges and special management areas	I
Areas identified in the North American Waterfowl Management Plan	I
Areas identified as significant under the RAMSAR Treaty	
Areas supporting rare or unique plant communities	
Areas designated as Sole Source Groundwater Aquifers	I
Areas protected by the Safe Drinking Water Act	
City, County, State, and National Parks	F, C, L
Areas supporting threatened or endangered species	B, C, E, G, I
Areas with unique geological features	
Areas protected by the Wild and Scenic Rivers Act	
Areas protected by the Wilderness Act	

[1] Program Authority / Agency
A = Bureau of Indian Affairs
B = National Marine Fisheries Service (NMFS)
C = U.S. Fish and Wildlife Service
D = National Park Service (NPS)
E = State Coastal Zone Office
F = State Departments of Natural Resources, Fish and Game, etc.
G = State Historic Preservation Officer (SHPO)
H = State Natural Heritage Offices
I = U.S. Environmental Protection Agency
J = Federal Emergency Management Administration
K = National Resource Conservation Service
L = Local Government Agencies

result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of wetland functions may be unnecessary since the project may be denied or modified strictly on the impacts to threatened or endangered species or habitat.

Define the Wetland Assessment Area

The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage, etc.). In many project areas, there will be just one WAA representing a single regional wetland subclass as illustrated in Figure 55. However, as the size and heterogeneity of the project area increases, it is more likely that it will be necessary to define and assess multiple WAAs within a project area.

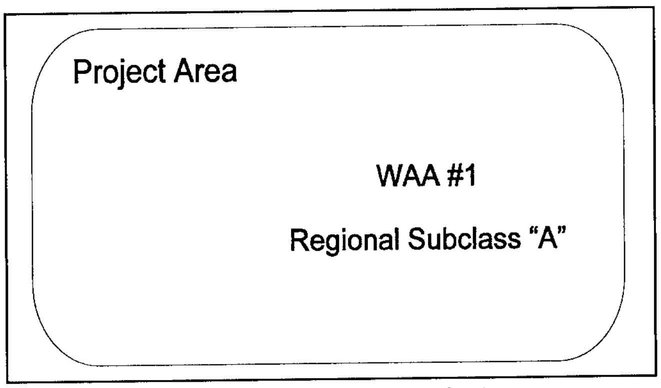

Figure 55. A single WAA within a project area

At least three situations necessitate defining and assessing multiple WAAs within a project area. The first situation exists when widely separated wetland patches of the same regional subclass occur in the project area (Figure 56). The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 57). The third situation exists when a physically contiguous wetland area of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into a significantly different value for one or more of the site-specific variable measures. These differences may be a result of natural variability (e.g., zonation on large river floodplains) or cultural alteration (e.g., logging, surface mining, hydrologic alterations) (Figure 58). Designate each of these areas as a separate WAA and conduct a separate assessment on each area.

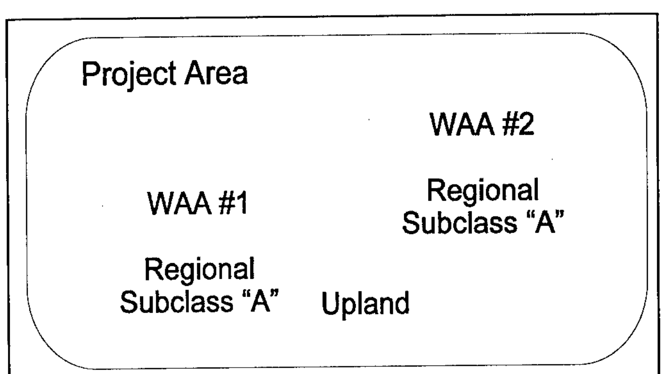

Figure 56. Spatially separated WAAs from the same regional wetland subclass within a project area

There are elements of subjectivity and practicality in determining what constitutes a "significant" difference in portions of the WAA. Field experience with the regional wetland subclass under

consideration should provide the sense of the range of variability that typically occurs and the "common sense" necessary to make reasonable decisions about defining multiple WAAs. For example, in western Tennessee, recently abandoned cropland and land harvested for timber will be two common criteria for designating two WAAs in a wetland area. Splitting an area into many WAAs in a project area, based on relatively minor differences, will lead to a rapid increase in sampling and analysis requirements. In general, differences resulting from natural variability should not be used as a basis for dividing a contiguous wetland area into multiple WAAs. However, zonation caused by different hydrologic regimes or disturbances caused by rare and destructive natural events (e.g., hurricanes) should be used as a basis for defining WAAs.

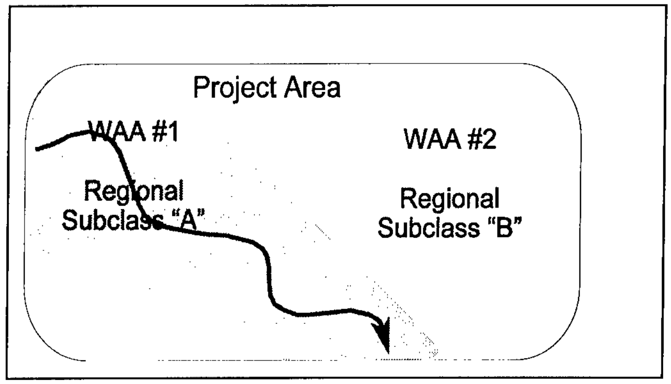

Figure 57. Spatially separated WAAs from different regional wetland subclasses within a project area

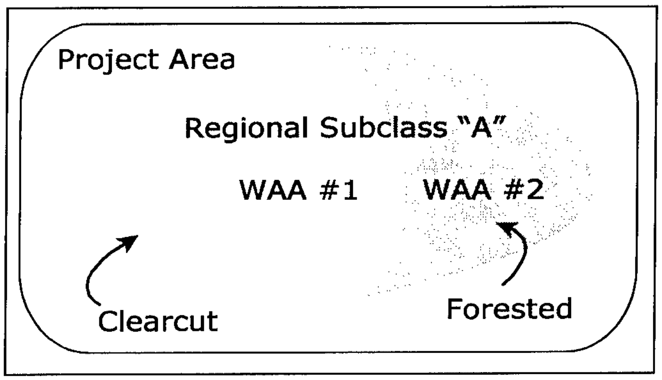

Figure 58. WAAs defined, based on differences in site-specific characteristics

Collect Field Data

The following equipment is necessary to collect field data.

a. Plant identification keys

b. Soil probe/sharpshooter shovel

c. Munsell color book and hydric soil indicator list (USDA NRCS 1998)

d. Diameter tape or calipers for measuring tree basal area

e. 50-m-distance measuring tape, stakes, and flagging

Information about the variables used to assess the functions of low gradient, riverine wetlands in western Tennessee is collected at several different spatial scales. The Field Data Sheet shown in Figure 59 is organized to facilitate data collection at each spatial scale. Information about landscape scale variables (i.e.,

Field Data Sheet: Low-Gradient Riverine Wetlands in Western Tennessee

Assessment Team : ____

Project Name/Location: ______________________________ Date :__________

Sample variables 1-6 using aerial photos, topographic maps, scenic overlooks, local informants, etc.

1. V_{TRACT} Area of the forest tract that is contiguous with the WAA . . . . _____ ha
2. V_{CORE} Percent of forest tract with a buffer of at least 300 m . . . . _____ %
3. $V_{CONNECT}$ Percent of wetland tract perimeter that is "connected" to suitable habitat . . . . _____ %
4. V_{SLOPE} Percent floodplain slope . . . . _____ %
5. V_{STORE} Floodplain width to channel width ratio . . . . _____
6. V_{MACRO} Percent of WAA covered with macrotopographic features . . . . _____ %

Sample variables 7-17 based on a walking reconnaissance of the WAA

7. V_{FREQ} Overbank flood recurrence interval . . . . _____ years
   Check data source: gage data __, local knowledge __, flood frequency curves __, regional dimensionless curve __, hydrologic modeling __, other ____________________.
8. V_{ROUGH} Roughness Coefficient ___ (n_{BASE}) + ___ (n_{TOPO}) + ___ (n_{OBS}) + ___ (n_{VEG}) = ... _____
9. $V_{SOILINT}$ Percent of WAA with altered soils . . . . _____ %.
10. V_{WTF} Water table fluctuation is (check one): . . . . present _____ absent _____
    Check data source: groundwater well, __ redoximorphic features, __ County Soil Survey __.
11. V_{WTD} Water table depth is . . . . _____ inches
    Check data source: groundwater well, __ redoximorphic features, __ County Soil Survey __.
12. $V_{WTSLOPE}$ Percent of WAA with an altered water table slope . . . . _____ %
13. $V_{SOILPERM}$ Soil permeability . . . . _____ (in/hr)
14. V_{PORE} Percent effective soil porosity . . . . _____ %
15. $V_{SURFCON}$ Percent of adjacent stream reach with altered surface connections . . . . _____ %
16. V_{CLAY} Percent of WAA with altered clay content in soil profile . . . . _____ %
17. V_{REDOX} Redoximorphic features are (check one): . . . . present _____ absent _____

Sample variables 18-20 in. from a representative number of locations in the WAA using a 0.04-ha circular plot (11.3-m (37-ft) radius)

18. V_{TBA} Tree basal area (average of 0.04-ha plot values on next line) . . . . _____ m^2/ha
    0.04-ha plots: 1 ____ m^2/ha 2 ____ m^2/ha 3 ____ m^2/ha 4 ____ m^2/ha
19. V_{TDEN} Number of tree stems (average of 0.04-ha plot values on next line) . . . . _____ stems / ha
    0.04-ha plots: 1 ____ stems/ha 2 ____ stems/ha 3 ____ stems/ha 4 ____ stems/ha
20. V_{SNAG} Number of snags (average of 0.04-ha plot values on next line) . . . . _____ stems / ha
    0.04-ha plots: 1 ____ stems/ha 2 ____ stems/ha 3 ____ stems/ha 4 ____ stems/ha

Sample variables 21-22 on two (2) 50-ft transects partially within the 0.04-ha plot

21. V_{WD} Volume of woody debris (average of transect values on next line) . . . . _____ m^3/ha
    Transect: 1 ____ m^3/ha 2 ____ m^3/ha 3 ____ m^3/ha 4 ____ m^3/ha
22. V_{LOG} Volume of logs (from Plot Worksheet) . . . . _____ m^3/ha
    Transect: 1 ____ m^3/ha 2 ____ m^3/ha 3 ____ m^3/ha 4 ____ m^3/ha

Sample variable 23 in two (2) 0.004-ha circular subplots (3.6-m (11.8-ft) radius) placed in representative locations of the 0.04-ha plot

23. V_{SSD} Number of woody understory stems (average of 0.04-ha plot values on next line)
    . . . . _____ stems / ha
    0.04-ha plots: 1 ____ stems/ha 2 ____ stem/ha 3 ____ stems/ha 4 ____ stems/ha

Figure 59. Sample Field Data Sheet (Continued)

Sample variables 24-26 in four (4) square meter subplots placed in representative locations of each quadrant of the 0.04-ha plot		
24. V_{GVC}	Average cover of ground vegetation . . . . Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %	____ %
25. V_{OHOR}	Average cover of "O" horizon . . . . Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %	____ %
26. V_{AHOR}	Average cover of "A" horizon (from plot worksheet) . . . . Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %	____ %
27. V_{COMP}	Concurrence with all strata dominants (from plot worksheet) . . . . Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %	____ %

Figure 59. (Concluded)

variables 1-6 on the Field Data Sheet), such as land use, is collected using aerial photographs, maps, and field reconnaissance of the area surrounding the WAA. Subsequently, information about the WAA in general (i.e., variables 7-17) is collected during a walking reconnaissance of the WAA. Finally, detailed site-specific information (i.e., variables 18-27) is collected using sample plots and transects at a number of representative locations throughout the WAA.

The layout for these plots and transects is shown in Figure 60. The exact number and location of these sample plots and transects are dictated by the size and heterogeneity of the WAA. If the WAA is relatively small (i.e., less than 2-3 acres) and homogeneous with respect to the characteristics and processes that influence wetland function, then three or four sample points in representative locations are probably adequate to characterize the WAA. However, as the size and heterogeneity of the WAA increases, more sample plots are required to accurately represent the site.

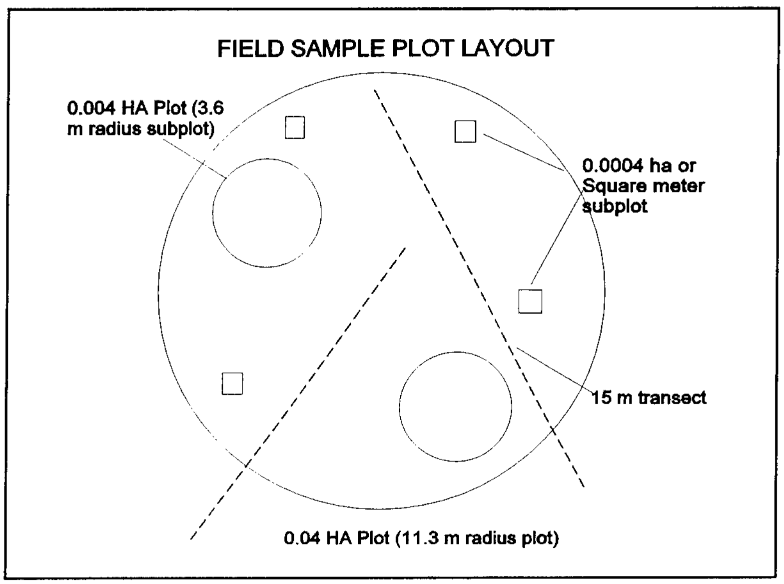

Figure 60. Sample plot and subplot dimensions and layouts for field sampling

Variables 18-20 are sampled using a circular 0.04-ha (0.01-acre) plot with a radius of 11.3 m. Variables 21 and 22 are sampled along two 15-m transects placed at least partially in the 0.04-ha plot. Variable 23 is sampled using two 0.004-ha (0.001-acre) plots placed in representative portions of the 0.04-ha plot. Variables 24-27 are sampled using four square meter plots placed in representative portions of each quadrant of the 0.04-ha plot.

For each location in the WAA where plot and transect data are collected (variables 18-27), a Plot Worksheet is filled out (Figure 61). Information from each Plot Worksheet is subsequently transferred to the Field Data Sheet prior to determining the final value for each variable. For example, in calculating variable V_{TBA} (#18) at each sampling location, begin by measuring the diameter at breast height of all trees in the 0.04-ha plot. Record these values by species in the table at the top of the Plot Worksheet, then convert these values to $m^2/0.04$ ha and sum. Carry the summed values down to the first line below the table and convert to m^2/ha. Transfer this value to the Field Data Sheet where all the m^2/ha values from the Plot Worksheet are summarized in the second line of the variable V_{TBA} (#18). To determine the final value of variable V_{TBA} (#18), average the m^2/ha values from each plot and transect sampling locations in the WAA. Complete instructions for collecting each variable in the field are provided in Appendix B along with a blank Plot Worksheet and Field Data Sheet.

As in defining the WAA, there are clearly an element of subjectivity and practical limitations in determining the number of sample locations for collecting plot and transect-based site-specific data. Experience has shown that the time required to complete an assessment at a several-acre WAA where 3-4 plots are sampled is 2-4 hr. Training and experience will reduce the required time to the lower end of this range.

Analyze Field Data

The analysis of field data requires two steps. The first step is to transform the measure of each assessment variable into a variable subindex. This can be done using the graphs in Appendix B or in a spreadsheet that has been set up to do the calculations automatically. The second step is to insert the variable subindices into the assessment model and calculate the FCI using the relationships defined in the assessment models. Again, this can be done manually or automatically, using a spreadsheet.

Figure 62 shows an example of a spreadsheet that has been set up to do both steps of the analysis. The data from the Field Data Sheet is transferred into the second column of the lower half of the spreadsheet to the right of the variable names. The calculated variable subindex is displayed in the fourth column of the lower half of the spreadsheet. The variable subindices are then used to calculate the FCI using the appropriate assessment model. The resulting FCI is displayed in the first column of the top half of the spreadsheet to the left of each function name. The spreadsheet format allows the user to instantly ascertain how a change in the field measure of a variable will affect the FCI of a particular

Plot Worksheet: Low-Gradient Riverine Wetlands in Western Tennessee

Assessment Team : ____

Project Name/Location : ______________________ Plot Number : _____ Date : ________

Record dbh (cm) of trees by species below, square dbh values (cm^2), multiply result by 0.000079 (m^2), and sum resulting values in shaded columns (m^2/0.04 ha). Record in 18. V_{TBA}, multiply by 25 (m^2/ha).

Species	dbh (cm)	dbh^2 (cm^2)	× 0.000079 (m^2/0.04 ha)	Species	dbh (cm)	dbh^2 (cm^2)	× 0.000079 (m^2/0.04 ha)

18. V_{TBA} Sum of values from shaded columns above = ______ (m^2/0.04 ha) × 25 = ________m^2/ha

19. V_{TDEN} Total number of tree stems from above = _______ (stems/0.04 ha) × 25 = ______stems/ha

20. V_{SNAG} Total number of snag stems from above= _____ (stems/0.04 ha) × 25 = ________stems/ha

21/22. V_{WD} /V_{LOG}

Record number of stems in Size Class 1 (0.6-2.5 cm / 0.25-1 in) along a 6 ft section of Transect 1 and 2

Transect 1 _______ Transect 2 _______ *Total number of stems* = _______

Size Class 1 tons /acre = 0.187 × *total number of stems* = ... _____ tons/acre

Record number of stems in Size Class 2 (2.5 - 7.6 cm / 1-3 in) along 12 ft section of Transect 1 and 2

Transect 1_______ Transect 2 _______ *Total number of stems* = _______

Size Class 2 tons / acre = 0.892 × *total number of stems* = ... _____ tons/acre

Record diameter of stems in Size Class 3 (> 7.6 cm / >3 in) along 50 ft section of Transect 1 and 2

Transect 1	diameter	diameter^2	Transect 2	diameter	diameter^2
Stem 1 =	_____	_____	Stem 1 =	_____	_____
Stem 2 =	_____	_____	Stem 2 =	_____	_____
Stem 3 =	_____	_____	Stem 3 =	_____	_____
Stem 4 =	_____	_____	Stem 4 =	_____	_____
Total diameter^2		_____	Total diameter ^{2}		_____

Total diameter^2 of stems from both transects = _____

Size Class 3 tons / acre = 0.0687 × *Total diameter ^{2} of stems from both transects* = _____ tons/acre

Total tons / acre (sum of Size Classes 1-3 from above) = ... _____ tons/acre

Cubic feet / acre = (32.05 × *total tons / acre*) / 0.58 = ... _____cubic feet/acre

Cubic meters / ha = *cubic feet / acre* × 0.069 . . . . _____ cubic meters/ha

Figure 61. Sample Plot Worksheet (Sheet 1 of 3)

23. V_{SSD}	Tally woody understory stems for two 0.004-ha subplots, then average and multiply by 250: Subplot 1 ________ Subplot 2 ________ Average ____ × 250 = ____ stems/ha
24. V_{GVC}	Estimate percent cover of ground vegetation in four m^2 subplots, then average: 1 ____% 2 ____% 3 ____% 4 ____% .... Average _____ %
25. V_{OHOR}	Estimate percent cover of "O" Horizon in four m^2 subplots, then average: 1 ____% 2 ____% 3 ____% 4 ____% .... Average _____ %
26. V_{AHOR}	Estimate percent cover of "A" Horizon in four m^2 subplots, then average: 1 ____% 2 ____% 3 ____% 4 ____% .... Average _____ %
27. V_{COMP}	Determine percent concurrence with each strata using the table below Tree = ___ % Shrub/Sapling = ___ % Ground Vegetation = ___ % Average _____ %

Dominant Species by Vegetation Strata by Zone in Reference Standard Sites in Western Tennessee

Zone	Tree	Shrub/Sapling	Ground Vegetation
Depression	*Nyssa aquatica*	*Carpinus caroliniana*	*Cornus foemina*
	Quercus lyrata	*Fraxinus pennsylvanica*	*Itea virginica*
	Taxodium distichum	*Nyssa aquatica*	*Saururus cernuus*
	Carya aquatica	*Quercus lyrata*	*Smilax rotundifolia*
		Itea virginica	*Peltandra virginica*
		Cornus foemina	
		Carya aquatica	
		Planera aquatica	
		Taxodium distichum	
Flat	*Carya glabra*	*Carpinus caroliniana*	*Arundinaria gigantea*
	Fraxinus pennsylvanica	*Carya glabra*	*Carex* spp.
	Liquidambar styraciflua	*Liquidambar styraciflua*	*Lobelia cardinalis*
	Quercus nigra	*Ulmus rubra*	*Smilax rotundifolia*
	Quercus michauxii	*Ulmus americana*	*Toxicodendron radicans*
	Quercus pagodaefolia	*Fraxinus pennsylvanica*	*Impatiens capensis*
	Quercus phellos	*Liquidambar styraciflua*	*Bignonia capreolata*
	Ulmus americana	*Quercus nigra*	*Boehmeria cylindrica*
		Quercus michauxii	*Aster simplex*
		Quercus pagodaefolia	*Vitis rotundifolia*
		Quercus phellos	*Vitis* spp.

(Continued)

Figure 61. (Sheet 2 of 3)

Zone	Tree	Shrub/Sapling	Ground Vegetation
Ridge	*Liquidambar styraciflua*	*Asimina triloba*	*Asimina triloba*
	Carya glabra	*Carpinus caroliniana*	*Arundinaria gigantea*
	Quercus alba	*Carya glabra*	*Boehmeria cylindrica*
	Quercus michauxii	*Carya ovata*	*Carex* spp.
	Quercus pagodaefolia	*Quercus nigra*	*Chasmanthium latifolium*
	Quercus phellos	*Ulmus americana*	*Toxicodendron radicans*
	Carya ovata	*Nyssa sylvatica*	*Bignonia capreolata*
	Quercus nigra	*Fagus grandifolia*	*Vitis rotundifolia*
	Ulmus americana	*Quercus shumardii*	*Vitis* spp.
	Nyssa sylvatica	*Ulmus rubra*	*Smilax rotundifolia*
	Fagus grandifolia	*Liquidambar styraciflua*	*Onoclea sensibilis*
	Quercus shumardii	*Carya glabra*	
	Ulmus rubra	*Quercus alba*	
		Quercus michauxii	
		Quercus pagodaefolia	
		Quercus phellos	

Notes:
Overlap of dominant species among zones may occur and is acceptable.
Species listed in the tree and shrub/sapling layers also may occur in the ground vegetation layer, but were not listed because of space.

Figure 61. (Sheet 3 of 3)

function by simply entering a new variable measure in the bottom half of the spreadsheet.

Apply Assessment Results

Once the assessment and analysis phases are complete, the results can be used to: (a) compare the same WAA at different points in time, (b) compare different WAAs at the same point in time, (c) compare different alternatives to a project, or (d) compare different hydrogeomorphic classes or subclasses as per Smith et al. (1995) and Davis (1998).

Variable Subindex and FCI Calculation for Low-Gradient Riverine Wetlands in Western Tennessee

FCI	Function
0.94	Temporarily Store Surface Water
0.94	Maintain Characteristic Subsurface Hydrology
0.81	Cycle Nutrients
0.90	Remove and Sequester Elements and Compounds
0.96	Retain Particulates
0.64	Export Organic Carbon
0.91	Maintain Characteristic Plant Community
0.88	Provide Habitat for Wildlife

>>>>>>> Enter quantitative or categorical measure from Field Data Sheet in shaded cells

Variables	Measure	Units	Subindex
1. *Vtract*	2000	ha	0.70
2. *Vcore*	50	%	0.71
3. *Vconnect*	50	%	1.00
4. *Vslope*	0.1	%	0.94
5. *Vstore*	50	%	0.91
6. *Vmacro*	10	no units	1.00
7. *Vfreq*	1.5	%	1.00
8. *Vrough*	2	no units	1.00
9. *Vpond*	45	%	1.00
10. *Vwtf*	1	present (1) or absent (0)	1.00
11. *Vwtd*	0	inches	1.00
12. *Vwtslope*	0	%	1.00
13. *Vsoilperm*	1	in/hr	1.00
14. *Vpore*	30	%	0.75
15. *Vsurfcon*	80	%	0.20
16. *Vclay*	40	%	0.60

Figure 62. Example of an FCI calculation spreadsheet

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Appendix A Glossary

"A" horizon: A mineral soil horizon at the soil surface or below an "O" horizon characterized by accumulation of humified organic matter intricately mixed with the mineral fraction.

Assessment model: A simple model that defines the relationship between ecosystem and land-scape scale variables and functional capacity of a wetland. The model is developed and calibrated using reference wetlands from a reference domain.

Assessment objective: The reason that an assessment of wetland functions is being conducted. Assessment objectives normally fall into one of three categories. These include: documenting existing conditions, comparing different wetlands at the same point in time (e.g., alternatives analysis), and comparing the same wetland at different points in time (e.g., impact analysis or mitigation success).

Assessment team (A-Team): An interdisciplinary group of regional and local scientists responsible for classification of wetlands within a region, identification of reference wetlands, construction of assessment models, definition of reference standards, and calibration of assessment models.

Channel: A natural stream or river or an artificial feature such as a ditch or canal that exhibits features of bed and bank and conveys water primarily unidirectionally down gradient.

Direct impacts: Project impacts that result from direct physical alteration of a wetland, such as the placement of dredge or fill.

Direct measure: A quantitative measure of an assessment model variable.

Functional assessment: The process by which the capacity of a wetland to perform a function is measured. This approach measures capacity using an assessment model to determine a functional capacity index.

Functional capacity: The rate or magnitude at which a wetland ecosystem performs a function. Functional capacity is dictated by characteristics of the wetland ecosystem, the surrounding landscape, and the interaction between the two.

Functional capacity index (FCI): An index of the capacity of a wetland to perform a function relative to other wetlands from a regional wetland subclass in a reference domain. Functional capacity indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates that a wetland performs a function at the highest sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in a reference domain. An index of 0.0 indicates the wetland does not perform the function at a measurable level and will not recover the capacity to perform the function through natural processes.

Highest sustainable functional capacity: The level of functional capacity achieved across the suite of functions by a wetland under reference standard conditions in a reference domain. This approach assumes that the highest sustainable functional capacity is achieved when a wetland ecosystem and the surrounding landscape are undisturbed.

Hydrogeomorphic wetland class: The highest level in the hydrogeomorphic wetland classification. There are five basic hydrogeomorphic wetland classes, including depression, fringe, slope, riverine, and flat.

Hydrogeomorphic unit: Hydrogeomorphic units are areas within a wetland assessment area that are relatively homogeneous with respect to ecosystem scale characteristics such as microtopography, soil type, vegetative communities, or other factors that influence function. Hydrogeomorphic units may be the result of natural or anthropogenic processes. See **Partial wetland assessment area.**

Indicator: Indicators are observable characteristics that correspond to identifiable variable conditions in a wetland or the surrounding landscape.

Indirect measure: A qualitative measure of an assessment model variable that corresponds to an identifiable variable condition.

Indirect impacts: Impacts resulting from a project that occur concurrently, or at some time in the future, away from the point of direct impact. For example, indirect impacts of a project on wildlife can result from an increase in the level of activity in adjacent, newly developed areas, even though the wetland is not physically altered by direct impacts.

In-kind mitigation: Mitigation in which lost functional capacity is replaced in a wetland of the same regional wetland subclass.

Interflow: The lateral movement of water in the unsaturated zone during and immediately after a precipitation event. The water, moving as interflow, discharges directly into a stream or lake.

Jurisdictional wetland: Areas that meet the soil, vegetation, and hydrologic criteria described in the "Corps of Engineers Wetlands Delineation Manual" (Environmental Laboratory 1987) or its successor.

Mitigation: Restoration or creation of a wetland to replace functional capacity that is lost as a result of project impacts.

Mitigation plan: A plan for replacing lost functional capacity resulting from project impacts.

Mitigation wetland: A restored or created wetland that serves to replace functional capacity lost as a result of project impacts.

Model variable: A characteristic of the wetland ecosystem or surrounding landscape that influences the capacity of a wetland ecosystem to perform a function.

"O" horizon: A layer with more than 12 to 18 percent organic C (by weight; 50 percent by volume). Form of the organic material may be recognizable plant parts (Oi) such as leaves, needles, twigs, moss, etc., partially decomposed plant debris (Oe), or totally decomposed organic material (Oa) such as muck.

Offsite mitigation: Mitigation that is done at a location physically separated from the site at which the original impacts occurred, possibly in another watershed.

Out-of-kind mitigation: Mitigation in which lost function capacity is replaced in a wetland of a different regional wetland subclass.

Partial wetland assessment area (PWAA): A portion of a WAA that is identified a priori, or while applying the assessment procedure, because it is relatively homogeneous and different from the rest of the WAA with respect to one or more model variables. The difference may occur naturally or as a result of anthropogenic disturbance. See **Hydrogeomorphic unit**.

Project alternatives: Different ways in which a given project can be done. Alternatives may vary in terms of project location, design, method of construction, amount of fill required, and other ways.

Project area: The area that encompasses all activities related to an ongoing or proposed project.

Project target: The level of functioning identified for a restoration or creation project. Conditions specified for the functioning are used to judge whether a project reaches the target and is developing toward site capacity.

Red flag features: Features of a wetland or the surrounding landscape to which special recognition or protection is assigned on the basis of objective criteria. The recognition or protection may occur at a Federal, State, regional, or local level and may be official or unofficial.

Reference domain: The geographic area from which reference wetlands are selected. A reference domain may, or may not, include the entire geographic area in which a regional wetland subclass occurs.

Reference standards: Conditions exhibited by a group of reference wetlands that correspond to the highest level of functional capacity (highest, sustainable level of functioning) across the suite of functions performed by the regional wetland subclass. The highest level of functional capacity is assigned an index value of 1.0 by definition.

Reference wetlands: Wetland sites that encompass the variability of a regional wetland subclass in a reference domain. Reference wetlands are used to establish the range of conditions for construction and calibration of functional indices and establish reference standards.

Region: A geographic area that is relatively homogeneous with respect to large scale factors such as climate and geology that may influence how wetlands function.

Regional wetland subclass: Wetlands within a region that are similar, based on hydrogeomorphic classification factors. There may be more than one regional wetland subclass identified within each hydrogeomorphic wetland class, depending on the diversity of wetlands in a region and the assessment objectives.

Site potential: The highest level of functioning possible, given local constraints of disturbance history, land use, or other factors. Site capacity may be equal to or less than levels of functioning established by reference standards for the reference domain, and it may be equal to or less than the functional capacity of a wetland ecosystem.

Throughflow: The lateral movement of water in an unsaturated zone during and immediately after a precipitation event. The water from throughflow seeps out at the base of slopes and then flows across the ground surface as return flow, ultimately reaching a stream or lake. See **Interflow** for comparison.

Value of wetland function: The relative importance of a wetland function to an individual or group.

Variable: An attribute or characteristic of a wetland ecosystem or the surrounding landscape that influences the capacity of the wetland to perform a function.

Variable condition: The condition of a variable as determined through quantitative or qualitative measure.

Variable index: A measure of how an assessment model variable in a wetland compares to the reference standards of a regional wetland subclass in a reference domain.

Wetland: See **Wetland ecosystems.**

Wetland ecosystems: In 404: ".......areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (Corps Regulation 33 CFR 328.3 and EPA Regulations 40 CFR 230.3). In a more general sense, wetland ecosystems are three-dimensional segments of the natural world where the presence of water, at or near the surface, creates conditions leading to the development of redoxomorphic soil conditions and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

Wetland assessment area (WAA): The wetland area to which results of an assessment are applied.

Wetland banking: The process of creating a "bank" of created, enhanced, or restored wetland to serve at a future date as mitigation for project impacts.

Wetland functions: The normal activities or actions that occur in wetland ecosystems, or simply, the things that wetlands do. Wetland functions result directly from the characteristics of a wetland ecosystem and the surrounding landscape and their interaction.

Wetland creation: The process of creating a wetland in a location where a wetland did not previously exist. Wetland creation is typically done for mitigation.

Wetland enhancement: The process of increasing the capacity of a wetland to perform one or more functions. Wetland enhancement can increase functional capacity to levels greater than the highest sustainable functional capacity achieved under reference standard conditions, but usually at the expense of sustainability or at a reduction of functional capacity of other functions. Wetland enhancement is typically done for mitigation.

Wetland restoration: The process of restoring wetland function in a degraded wetland. Restoration is typically done as mitigation.

Wetland values: See **Value of wetland function**.

Appendix B
Summaries and Forms for Field Use

This appendix contains the following information summaries and example sheets:

a. Summary of Functions for Low-Gradient Riverine Wetlands - page B2

b. Summary of Model Variables, Measure/Units, and Methods - page B7

c. Summary of Variables by Function - page B26

d. Summary of Graphs for Transforming Measures to Subindices in the Flats Zone-page B28

e. Summary of Graphs for Transforming Measures to Subindices in the Depression Zone-page B33

f. Summary of Graphs for Transforming Measures to Subindices in the Ridge Zone-page B38

g. Blank Field Data Sheet - page B43

h. Blank Plot Worksheet - page B45

Summary of Functions for Low-Gradient Riverine Wetlands

Function 1: Temporarily Store Surface Water

a. Definition. The function Temporarily Store Surface Water is defined as the capacity of a riverine wetland to temporarily store and convey floodwaters that inundate riverine wetlands during overbank flow events. The water that is stored and conveyed usually originates as overbank flows from an adjacent stream channel. However, other potential contributing sources of water include: (1) precipitation, (2) surface water from adjacent uplands transported to the wetland via surface channels or overland flow, and (3) subsurface water from adjacent uplands transported to the wetland as interflow or shallow groundwater and discharging at the edge, or interior, of the floodplain. A potential independent, quantitative measure for validating the functional index is the volume of water stored per unit area per unit time (m^3/ha/time) at a discharge that is equivalent to the average annual peak event.

b. Model variables - symbols - measures - units.

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(2) Floodplain storage volume - V_{STORE} - floodplain width/channel width - unitless.

(3) Floodplain slope - V_{SLOPE} - change in elevation/prescribed distance along center line - unitless.

(4) Floodplain roughness - V_{ROUGH} - Manning's roughness coefficient *(n)* - unitless.

c. Assessment model:

$$FCI = \left[\left(V_{FREQ} \times V_{STORE} \right)^{1/2} \times \left(\frac{V_{SLOPE} + V_{ROUGH}}{2} \right) \right]^{1/2}$$

Function 2: Maintain Characteristic Subsurface Hydrology

a. Definition. Maintain Characteristic Subsurface Hydrology is defined as the capacity of a riverine wetland to store and convey subsurface water. Potential sources for subsurface water in riverine wetlands are direct precipitation, interflow (i.e., unsaturated subsurface flow), groundwater (i.e., saturated subsurface flow), and overbank flooding. A potential independent, quantitative measure for validating the functional index is the number of days each year that a characteristic depth to water table is maintained.

b. Model variables - symbols - measures - units:

(1) Subsurface water velocity - $V_{SOILPERM}$ - soil permeability - inches/hour.

(2) Water table slope - $V_{WTSLOPE}$ - percent of area being assessed with an altered water table slope - unitless.

(3) Subsurface storage volume - V_{PORE} - percent effective soil porosity - unitless.

(4) Water table fluctuation - V_{WTF} - presence/absence of fluctuating water table - unitless.

c. *Assessment model:*

$$FCI = \left[\frac{\left(V_{SOILPERM} \times V_{WTSLOPE}\right)^{1/2} + \left(\frac{V_{PORE} + V_{WTF}}{2}\right)}{2} \right]$$

Function 3: Cycle Nutrients

a. *Definition.* Cycle Nutrients is defined as the ability of the riverine wetland to convert nutrients from inorganic forms to organic forms and back, through a variety of biogeochemical processes such as photosynthesis and microbial decomposition. Potential independent, quantitative measures for validating the functional index include net annual primary productivity (gm/m^2), annual litter fall (gm/m^2), or standing stock of living and/or dead biomass (gm/m^2).

b. *Model variables - symbols - measures - units*:

(1) Tree biomass - V_{TBA} - tree basal area - m^2/ha.

(2) Understory vegetation biomass - V_{SSD} - density of understory woody stems - stems/ha.

(3) Ground vegetation biomass - V_{GVC} - percent cover of ground vegetation - unitless.

(4) "O" horizon biomass - V_{OHOR} - percent cover of "O" soil horizon cover - unitless.

(5) "A" horizon biomass -V_{AHOR} - percent cover of "A" soil horizon - unitless.

(6) Woody debris biomass - V_{WD} - volume of woody debris - m^3/ha.

c. *Assessment model:*

$$FCI = \left[\frac{\left(\frac{V_{TBA} + V_{SSD} + V_{GVC}}{3}\right) + \left(\frac{V_{OHOR} + V_{AHOR} + V_{WD}}{3}\right)}{2} \right]$$

Function 4: Remove and Sequester Elements and Compounds

a. *Definition.* Removal and Sequestration of Elements and Compounds is defined as the ability of the riverine wetland to permanently remove or temporarily immobilize nutrients, metals, and other elements and compounds that are imported to the riverine wetland from upland sources and via overbank flooding. In a broad sense, elements include macronutrients essential to plant growth (nitrogen, phosphorus, and potassium) and other elements such as heavy metals (zinc, chromium, etc.) that can be toxic at high concentrations. Compounds include pesticides and other imported materials. The term "removal" means the permanent loss of elements and compounds from incoming water sources (e.g., deep burial in sediments, loss to the atmosphere), and the term "sequestration" means the short- or long-term immobilization of elements and compounds. A potential independent, quantitative measure of this function is the quantity of one or more imported elements and compounds removed or sequestered per unit area during a specified period of time (e.g., $g/m^2/yr$).

b. *Model variables - symbols - measures - units*:

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years

(2) Water table depth - V_{WTD} - depth to seasonal high water table - inches.

(3) Soil clay content -V_{CLAY} - percent difference of soil clay content - unitless.

(4) Redoximorphic features - V_{REDOX} - presence/absence of redoximorphic features - unitless.

(5) "O" horizon biomass - V_{OHOR} - percent cover of "O" soil horizon - unitless.

(6) "A" horizon biomass - V_{AHOR} - percent cover of "A" soil horizon - unitless

c. *Assessment model:*

$$FCI = \left[\left(\frac{V_{FREQ} + V_{WTD}}{2} \right) \times \left(\frac{V_{CLAY} + V_{REDOX} + V_{OHOR} + V_{AHOR}}{4} \right) \right]^{1/2}$$

Function 5: Retain Particulates

a. *Definition.* The Retain Particulates function is the capacity of a wetland to physically remove and retain inorganic and organic particulates (>0.45 μm) from the water column. Retention applies to particulates arising from both onsite and offsite sources. The quantitative measure of this function is the amount of particulates per unit area per unit time (e.g., $g/m^2/yr$).

b. *Model variables - symbols - measures - units*:

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(2) Floodplain storage volume - V_{STORE} - floodplain width/channel width - unitless.

(3) Floodplain slope - V_{SLOPE} - change in elevation/prescribed distance along center line - unitless.

(4) Floodplain roughness - V_{ROUGH} - Manning's roughness coefficient (*n*) - unitless.

c. *Assessment model*:

$$FCI = \left[\left(V_{FREQ} \times V_{STORE} \right)^{1/2} \times \left(\frac{V_{SLOPE} + V_{ROUGH}}{2} \right) \right]^{1/2}$$

Function 6: Export of Organic Carbon

a. *Definition.* This function is defined as the capacity of the wetland to export dissolved and particulate organic carbon produced in the riverine wetland. Mechanisms include leaching of litter, flushing, displacement, and erosion. An independent quantitative measure of this function is the mass of carbon exported per unit area per unit time (e.g., $g/m^2/yr$).

b. *Model variables - symbols - measures - units*:

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(2) Surface water connections - $V_{SURFCON}$ - percent of linear distance of altered stream reach - unitless.

(3) "O" horizon biomass - V_{OHOR} - percent cover of "O" soil horizon cover - unitless.

(4) Woody debris biomass - V_{WD} - volume of woody debris - m^3/ha.

c. *Assessment model:*

$$FCI = \left[\left(V_{FREQ} \times V_{SURFCON} \right)^{1/2} \times \left(\frac{V_{OHOR} + V_{WD}}{2} \right) \right]^{1/2}$$

Function 7: Maintain Characteristic Plant Community

a. *Definition.* Maintain Characteristic Plant Community is defined as the capacity of a riverine wetland to provide the environment necessary for a characteristic plant

community to develop and be maintained. In assessing this function, one must consider both the extant plant community as an indication of current conditions and the physical factors that determine whether or not a characteristic plant community is likely to be maintained in the future. Potential independent, quantitative measures of this function based on vegetation composition/abundance include similarity indices (Ludwig and Reynolds 1988)[1] or ordination axis scores from detrended correspondance analysis or other multivariate technique (Kent and Coker 1995). A potential independent quantitative measure of this function based on both vegetation composition/abundance and environmental factors is ordination axis scores from canonical correlation analysis (ter Braake 1994).

b. Model variables - symbols - measures - units:

(1) Tree biomass - V_{TBA} - tree basal area - m^2/ha.

(2) Tree density - V_{TDEN} - tree density - stems/ha.

(3) Plant species composition - V_{COMP} - percent concurrence with dominant species by strata - unitless.

(4) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(5) Water table depth - V_{WTD} - depth to seasonal high water table - inches.

(6) Soil integrity - $V_{SOILINT}$ - percent of area with altered soil - unitless.

c. Assessment model:

$$FCI = \left[\frac{\left(\frac{V_{TBA} + V_{TDEN}}{2} \right) + V_{COMP}}{2} \times \frac{V_{SOILINT} + V_{FREQ} + V_{WTD}}{3} \right]^{1/2}$$

Function 8: Provide Habitat for Wildlife

a. Definition. The function Provide Habitat for Wildlife reflects the ability of a riverine wetland to support the wildlife species that utilize riverine wetlands during some part of their life cycles. The focus of this model is on avifauna, based on the assumption that, if conditions are appropriate to support the full complement of avian species found in reference standard wetlands, the requirements of other animal groups (e.g., mammals, reptiles, and amphibians) will be met. A potential independent, quantitative measure of this function is a similarity index calculated from species composition and abundance (Odum 1950, Sorenson 1948).

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[1] References cited in this appendix are listed in the References at the end of the main text.

b. Model variables - symbols - measures - units:

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(2) Macrotopographic features - V_{MACRO} - percent of area with macrotopographic features - unitless.

(3) Plant species composition - V_{COMP} - percent concurrence with dominant species by strata - unitless.

(4) Tree biomass - V_{TBA} - tree basal area - m^2/ha.

(5) Tree density - V_{TDEN} - tree density - stems/ha.

(6) Log biomass - V_{LOG} - volume of logs - m^3/ha.

(7) Snag density - V_{SNAG} - snag density - stems/ha.

(8) "O" horizon biomass - V_{OHOR} - percent cover of "O" soil horizon cover - unitless.

(9) Wetland tract - V_{TRACT} - size of forest tract - ha.

(10) Interior core area -V_{CORE} - percent of forest tract with 300-m buffer - unitless.

(11) Habitat connections - $V_{CONNECT}$ - percent of wetland tract perimeter connected - unitless.

c. Assessment model:

$$FCI = \left[\frac{\left(\frac{V_{FREQ} + V_{MACRO}}{2}\right) + \left(\frac{V_{TRACT} + V_{CONNECT} + V_{CORE}}{3}\right)}{2} \times \frac{V_{COMP} + V_{TBA} + V_{TDEN} + \left(\frac{V_{LOG} + V_{SNAG} + V_{OHOR}}{2}\right)}{4} \right]^{1/2}$$

Summary of Model Variables, Measure/Units, and Methods

1. Forest tract (V_{TRACT})

Measure/Units: The area of forest in hectares that is contiguous with the WAA.

Method: (1) Determine the size of the area of wetland of the same regional subclass that is contiguous with the assessment area using field reconnaissance, topographic maps, National Wetland Inventory maps (NWI), or aerial photography.

(2) Report the size of the wetland tract in hectares.

2. Interior core area (V_{CORE})

Measure/Units: The percent of the forest tract with a buffer zone >300 m separating it from nonforested habitat.

Method: (1) Determine the area of the forest tract within a buffer of at least 300 m using field reconnaissance, topographic maps, NWI maps, aerial photography, or other sources.

(2) Divide the area within the buffer by the total size of the forest tract and multiply by 100. The result is the percentage of the wetland tract within a buffer zone >300 m.

(3) Report the size of the area within a 300-m buffer as a percentage of total tract area.

3. Habitat connections ($V_{CONNECT}$)

Measure/Units: The percent of the perimeter of the wetland tract that is "connected" to the total length of the perimeter of the wetland.

Method: (1) Determine the total length of the wetland perimeter using field reconnaissance, topographic maps, or aerial photography.

(2) Determine the length of the wetland perimeter that is "connected" to suitable habitats such as other wetlands, upland forests, or other wildlife habitats.

(3) Divide the length of "connected" wetland perimeter by the total length of the wetland perimeter.

(4) Convert to a percent of the perimeter by multiplying by 100.

(5) Report as the percent of the perimeter of the wetland tract that is "connected"

4. Floodplain slope (V_{SLOPE})

Measure/Units: Percent floodplain slope.

Method: (1) Determine the change in elevation between two points along the floodplain center line (i.e, center line of the meander belt of the active channel) on a river

reach representative of the area being assessed (Figure 8, main text). This can be accomplished using the contour lines on a standard 7.5-minute USGS topographic map. The distance between the two points should be great enough so that local anomalies in floodplain slope do not influence the result. As a rule of thumb, the line between the two points should intersect at least two contour lines on a 1:24,000 scale (7.5-minute) USGS topo map.

(2) Determine the distance between the two points.

(3) Divide the change in elevation by the distance between the two points. For example, if the change in elevation between the two points is 3 m (10 ft) and the distance between the two points is 1 mile (1,609 m) (5,280 ft) the slope is 3m/1,609 m = 0.002 (10 ft/5,280 ft = 0.002).

(4) Convert the slope to a percent slope by multiplying by 100.

(5) Report floodplain slope as a percent.

5. Floodplain storage volume (V_{STORE})

Measure/Units: The ratio of floodplain width to channel width (i.e., floodplain width/channel width).

Method: (1) Measure the width of the floodplain and the width of the channel using surveying equipment or by pacing in the field (Figure 6, main text). A crude estimate can be made using topographic maps, or aerial photos, remembering that short distances on maps and photographs translate into long distances on the ground (e.g., a section line on a 1:24,000 USGS topographic map represents about 9.1 m (30 ft) on the ground).

(2) Calculate the ratio by dividing the floodplain width by the channel width.

(3) Report the ratio of floodplain width to channel width as a unitless number.

6. Macrotopographic features (V_{MACRO})

Measure/Units: The percent of the WAA occupied by macrotopographic features.

Method: (1) If the area being assessed is greater than 1 km^2, the percentage of the area that consists of macrotopographic features is used to quantify this variable. Measure it with the procedure outlined under Alternative 1 if the area being assessed is greater than 1 km^2 or Alternative 2 if the area is less than 1 km^2.

(a) Alternative 1: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in the assessment area.

(b) Alternative 2: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in a 1-km^2 area around the assessment area. For instance, a 1-km^2 template can be placed on a map or aerial photograph of appropriate scale and the percentage of that area covered by macrotopographic features can be estimated.

(2) Report the percentage of the area being assessed that is covered with macrotopographic features.

7. Overbank flood frequency (V_{FREQ})

Measure/Units: Recurrence interval in years.

Method: (1) Use one of the following methods to determine recurrence interval with the guidelines provided in Appendix C:

(a) Data from a nearby stream gage;

(b) Regional flood frequency curves developed by local and State offices of USACE, USGS-Water Resources Division, State Geologic Surveys, or NRCS (Jennings, Thomas, and Riggs 1994);

(c) Hydrologic models such as HEC-2 (U.S. Army Corps of Engineers 1981, 1982), HECRAS (U.S. Army Corps of Engineers 1997), HSPF (Bicknell et al. 1993);

(d) Local knowledge; or

(e) Regional dimensionless rating curve (Pruitt and Nutter unpublished manuscript).

(2) Report recurrence interval in years.

8. Floodplain roughness (V_{ROUGH})

Measure/Units: Manning's roughness coefficient *(n)*.

Method: (1) Alternative 1 (not recommended): Compare the area to be assessed to the photographs of forested floodplains presented in Arcement and Schneider (1989). These photographs illustrate a variety of conditions for which Manning's roughness coefficient has been calculated empirically and can be used in the field to estimate Manning's roughness coefficient for sites that are well stocked with trees.

(2) Alternative 2: Use Arcement and Schneider's (1989) method for estimating Manning's roughness coefficient based on a characterization of the different

components that contribute to roughness on floodplains which include: micro- and macrotopographic relief (n_{TOPO}), obstruction (n_{OBS}), and vegetation (n_{VEG}). Complete the following steps:

(a) Determine the value of n_{BASE} (i.e., the contribution to roughness of bare soil). Arcement and Schneider (1989) suggest using 0.03, the value for firm soil.

(b) Using the descriptions in Table B1, assign an adjustment value to the roughness components of n_{TOPO}, n_{OBS}, and n_{VEG}.

(c) Sum the values of the roughness components.

Table B1
Adjustment Values for Roughness Components

Roughness Component	Adjustment to *n* value	Description of Conditions
Topographic relief (n_{TOPO})	0.0	Representative area is flat with essentially no microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales).
	0.005	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers 5-25% of a representative area.
	0.01	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers 26-50% of a representative area.
	0.02	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers >50% of a representative area.
Obstructions (n_{OBS}) (includes coarse woody debris, stumps, debris deposits, exposed roots)	0.0	No obstructions present
	0.002	Obstructions occupy 1-5% of a representative cross-sectional area.
	0.01	Obstructions occupy 6-15% of a representative cross-sectional area.
	0.025	Obstructions occupy 16-50% of a representative cross- sectional area.
	0.05	Obstructions occupy >50% of a representative cross-sectional area.
Vegetation (n_{VEG})	0.0	No vegetation present
	0.005	Representative area covered with dense herbaceous or woody vegetation where depth of flow exceeds height of vegetation by 3 times.
	0.015	Representative area covered with dense herbaceous or woody vegetation where depth of flow exceeds height of vegetation by by 2-3 times.
	0.05	Representative area covered with herbaceous or woody vegetation where depth of flow is at height of vegetation.
	0.1	Representative area fully stocked with trees and with sparse herbaceous or woody understory vegetation.
	0.15	Representative area partially to fully stocked with trees and with dense herbaceous or woody understory vegetation.

(3) Report Manning's roughness coefficient (n) as a unitless number.

9. Soil integrity ($V_{SOILINT}$)

Measure/Units: The percent of the WAA with altered soils.

Method:

(1) Determine if any of the soils in the area being assessed have been altered. In particular look for alteration to a normal soil profile. For example, absence of an "A" horizon, presence of fill material, or other types of impact that significantly alter soil integrity.

(2) If no altered soils exist, assign the variable subindex a value of 1.0. This indicates that all of the soils in the assessment area are similar to soils in reference standard sites.

(3) If altered soils exist, determine what percent of the assessment area has soils that have been altered.

(4) Report the percent of the assessment area with altered soils.

10. Water table fluctuation (V_{WTF})

Measure/Units: Presence or absence of a fluctuating water table.

Method:

(1) Determine the presence or absence of a fluctuating water table using the following (in order of accuracy and preference):

(a) Monitored groundwater well data;

(b) Redoximorphic features such as oxidized rhizospheres, reaction to *a, a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994, Hurt, Whited, and Pringle 1996), remembering that some redoximorphic features reflect that a soil has been anaerobic at some time in the past but do not necessarily reflect current conditions;

(c) The presence of a fluctuating seasonal high water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the Soil Survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

(2) Report fluctuating water table as present or absent.

11. Water table depth (V_{WTD})

Measure/Units: Depth to the seasonal high water table in inches.

Method:

(1) Determine the depth to the seasonal high water table using the following (in order of accuracy and preference):

(a) Monitored groundwater well data;

(b) Redoximorphic features such as oxidized rhizospheres, reaction to *a, a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994, Hurt, Whited, and Pringle 1996), remembering that some redoximorphic features reflect that a soil has been anaerobic at some time in the past but do not necessarily reflect current conditions;

(c) The presence of a fluctuating seasonal high water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the Soil Survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

(2) Report the depth to the seasonal high water table in inches.

12. Water table slope ($V_{WTSLOPE}$)

Measure/Units: The percent of the WAA with an altered water table slope.

Method:

(1) Determine if the slope of the ground surface has been altered, by ditching, tiling, dredging, channelization, or other activities with the potential to modify the water table slope.

(2) If the slope of the water table has not been altered, the percent of the area altered is 0.0.

(3) If the water table slope has been altered in any portion of the area being assessed, determine the soil type and the "depth of the alteration." For example, if the ditch has been dug, the depth of the alteration is the depth of the ditch measured from the original ground surface (Figure 13, main text). If a stream channel has been dredged, the depth of the alteration is the difference between the old and new channel depth.

(4) Use Table B2 to determine the lateral distance that will be affected by the alteration. For example, if the soil is in the Tichnor series and the depth of the alteration is 50 cm (1.52 ft), the lateral ditch effect is 77 m (252 ft). The

procedures used to calculate the values in this table are based on the van Schilfgaarde Equation (USDA NRCS 1977) described in Appendix C.

Table B2
Lateral Effect of Ditches in Meters (ft) for Selected Soil Series in Western Tennessee

	Depth of Ditch or Change in Depth of Channel, cm									
Soil Series	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**150**	**200**	**250**
Adler	55 (181)	56 (184)	57 (186)	58 (188)	58 (189)	58 (191)	58 (192)	59 (193)	59 (194)	59 (194)
Arkabutla	69 (266)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	130 (426)	156 (512)	172 (566)	182 (597)
Collins	69 (226)	84 (275)	89 (291)	93 (306)	93 (307)	93 (307)	93 (307)	93 (307)	93 (307)	93 (307)
Convent	45 (147)	46 (152)	47 (156)	48 (157)	48 (157)	48 (159)	49 (160)	50 (166)	51 (169)	51 (169)
Dekoven	69 (226)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	124 (407)	127 (418)	132 (434)	133 (434)
Falaya	78 (256)	84 (275)	89 (291)	93 (306)	97 (320)	98 (321)	98 (322)	98 (323)	99 (324)	99 (324)
Oaklimeter	69 (226)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	124 (407)	124 (407)	124 (407)	124 (407)
Robinsonville	42 (139)	46 (152)	47 (156)	48 (159)	50 (163)	50 (164)	51 (168)	53 (174)	54 (177)	54 (177)
Rosebloom	69 (226)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	130 (426)	156 (511)	172 (566)	182 (597)
Tichnor	62 (204)	77 (252)	88 (289)	97 (320)	105 (346)	107 (352)	109 (358)	110 (361)	110 (361)	110 (361)
Vacherie	69 (226)	84 (275)	96 (315)	106 (348)	115 (376)	123 (402)	124 (407)	127 (418)	132 (434)	133 (434)
Waverly	69 (226)	84 (275)	89 (291)	93 (306)	102 (336)	106 (348)	106 (348)	106 (348)	106 (348)	106 (348)

(5) Using the lateral distance of the effect and the length of the alteration, estimate the size of the area that will be affected by the alteration. For example, if the lateral effect of the ditch is 77 m (252 ft) and the ditch is 15.2 m (50 ft) long, the area affected is $77 \times 15.2 = 1170$ m^2 (0.117 ha) (0.29 acres).

(6) Calculate the ratio of the size of all areas within the area being assessed that are affected by an alteration to the water table slope to the size of the entire area being assessed. For example, if the area affected by the alteration is 0.117 ha (0.29 acres), and the area being assessed is 4 ha (10 acres), the ratio is $0.117/4 = 0.029$ ($0.29/10 = 0.029$).

(7) Multiply the ratio by 100 to obtain the percentage of the area being assessed with an altered water table slope.

(8) Report the percent of the area being assessed with an altered water table slope.

13. Subsurface water velocity ($V_{SOILPERM}$)

Measure/Units: Soil permeability in inches per hour.

Method: (1) Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in construction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

(2) If soils have been altered, select one of the two following alternatives, otherwise skip this step.

(a) Assign a value to soil permeability based on a representative number of field measurements of soil permeability. The number of measurements will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(b) Assign a variable subindex based on the category of alteration that has occurred at the site using the information in Table B3. (Note: in this particular situation, no value is assigned to soil permeability, rather, a variable subindex is assigned directly.)

Table B3
Variable Subindices for Altered Soils

Alteration Category	"Typical" Soil Permeability After Alteration	Average Depth of Alteration Effects	Variable Subindex
Silviculture: normal activities compact surface layers and reduce permeability to a depth of about 6 in. (Aust 1994)	highly variable and spatially heterogeneous	top 6 in. of soil profile	0.7
Agricultural Tillage: some surface compaction occurs as well as a general decrease in the average size of pore spaces which decreases the ability of water to move through the soil to depth of about 6 in. (Drees et al. 1994).	highly variable and spatially heterogeneous	top 6 in. of soil profile	0.7
Construction Activities / Surface Mining: compaction resulting from large equipment over the soil surface, cover of soil surface with pavement or fill material, or excavation and subsequent replacement of heterogeneous materials	highly variable and spatially heterogeneous	entire soil profile	0.1

(3) If the soils have not been altered, select one of the two following alternatives.

(a) Assign a value to soil permeability based on a representative number of field measures of soil permeability. The number of field measures will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(b) Assign a value to soil permeability by calculating the weighted average of median soil permeability to a depth of 20 in. Information for the soil series that occur in western Tennessee riverine wetlands is in Table B4. Calculate the weighted average of median soil permeability by averaging the median soil permeability values to a depth of 20 in. For example, in Table B4, the Waverly series has a median soil permeability value from a

depth of 0-20 in. of 1.3. Thus, the weighted average of the median soil permeability for the top 20 in. is $(20 \times 1.3) / 20 = 1.3$.

(4) Report soil permeability in inches/hour.

Table B4
Soil Permeability at Different Depths for Soil Series in Western Tennessee

Soil Series	Depth, cm (in.)	Range of Soil Permeability, cm (in.) per hr	Weighted Average Soil Permeability in top 50.8 cm (20 in.), cm (in.) per hr
Adler	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Arkabutla	0-50.8 (0-20)	0.5-1.5 (0.2-0.6)	3.3 (1.3)
Collins	0-50.8 (0-20)	0.5-1.5 (0.2-0.6)	3.3 (1.3)
Convent	0-50.8 (0-20)	0.5-1.5 (0.2-0.6)	3.3 (1.3)
Falaya	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Oaklimeter	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Robinsonville	0-17.8 (0-7)/17.9-50.8 (7.1-20)	5.1-15.2 (2.0-6.0)/1.5-15.2 (0.6-6.0)	7.1 (2.8)
Rosebloom	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Tichnor	0-15.2 (0-6)/15.3-50.8 (6.1-20)	1.5-5.1 (0.6-2.0)/0.5-5.1 (0.2-0.6)	2.9 (1.1)
Waverly	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)

14. Subsurface storage volume (V_{PORE})

Measure/Units: Percent effective soil porosity is the measure of this variable.

Method: (1) Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in construction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

(2) If soils have been altered:

(a) Assign a value to soil permeability based on a representative number of field measures of soil bulk density. The number of field measures will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for using measurements of bulk density to determine effective soil porosity.

(b) Assign a variable subindex based on the category of alteration that has occurred at the site shown in Table B3. (Note: in this particular situation, no value is assigned to the metric, rather, a variable subindex is assigned directly.)

(3) If the soils have not been altered, quantify percent effective soil porosity using one of the following options.

(a) Collect a representative number of field measures of bulk density and use the procedure outlined in Appendix C to determine percent effective soil porosity. The number of field measures of bulk density will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties.

(b) Use the percent effective soil porosity values for particular soil series provided in Table B5. The procedures used to calculate the values in this table are provided in Appendix C.

(4) Report subsurface storage volume as percent effective soil porosity.

Table B5
Soil Series and Effective Soil Porosity Values

Soil Series	Median Bulk Density, g/cm^3	Total Porosity %	Residual Water Content, %	Effective Soil Porosity, %	Soil Texture
Adler	1.53	42	1.5	40.5	SiL
Arkabutla	1.45	45	2.7	42.3	SiL/SCL
Collins	1.45	45	1.5	43.5	SiL
Convent	1.48	44	3.4	40.6	S/VFSL
Falaya	1.35	49	1.5	47.5	SiL
Oaklimeter	1.45	45	1.5	43.5	SiL
Robinsonville	1.45	45	3.4	41.6	VFSL/L
Rosebloom	1.47	44	1.5	42.5	SiL
Tichnor	1.43	46	1.5	44.5	SiL
Waverly	1.45	45	1.5	43.5	SiL

15. Surface water connections ($V_{SURFCON}$)

Measure/Units: The percent of the linear distance of stream reach adjacent to the WAA that has been altered is the measure of this variable.

Method: (1) Conduct a visual reconnaissance of the WAA and the adjacent stream reach. Estimate what percent of this stream reach has been modified with levees, side cast materials, or other obstructions that reduce the exchange of surface water between the stream channel and the riverine wetland.

(2) Report percent of the linear distance of the stream reach that has been altered.

16. Soil clay content (V_{CLAY})

Measure/Units: The difference in clay content in the top 50.8 cm (20 in.) of the soil profile in the WAA is used to quantify this variable.

Method:

(1) Determine if the native soil in any of the area being assessed has been covered with fill material, excavated and replaced, or subjected to any other types of impact that significantly change the clay content of the top 50.8 cm (20 in.) of the soil profile. If no such alteration has occurred, assign the variable subindex a value of 1.0 and move on to the next variable. A value of 1.0 indicates that none of the soils in the area being assessed have an altered clay content in the top 50.8 cm (20 in.).

(2) If the soils in the part of the area being assessed have been altered in one of the ways described above, estimate the soil texture for each soil horizon in the upper 50.8 cm (20 in.) in representative portions of these areas. Soil particle size distribution can be measured in the laboratory on samples taken from the field, or the percent of clay can be estimated from field texture determinations done by the "feel" method. Appendix C describes the procedures for estimating texture class by feel.

(3) Based on the soil texture class determined in the previous step, the percentage of clay is determined from the soil texture triangle. The soil texture triangle contains soil texture classes and the corresponding percentages of sand, silt, and clay that comprise each class. Once the soil texture is determined by feel, the corresponding clay percentage is read from the left side of the soil texture triangle. The median value from the range of percent clay is used to calculate the weighted average. For example, if the soil texture at the surface is a silty clay loam, the range of clay present in that texture class is 28-40 percent. A median value of 34 percent would be used for the clay percentage in that particular horizon.

(4) Calculate a weighted average of the percent clay in the altered soil by averaging the percent clay from each of the soil horizons to a depth of 50.8 cm (20 in.). For example, if the "A" horizon occurs from a depth of 0-12.7 cm (0-5 in.) and has 30 percent clay, and the B horizon occurs from a depth of 15.2-50.8 cm (6-20 in.) and has 50 percent clay, then the weighted average of the percent clay for the top 50.8 cm (20 in.) of the profile is $((5 \times 30) + (15 \times 50)) / 20 = 45$ percent.

(5) Calculate the difference in percent clay between the natural soil (i.e., what existed prior to the impact) and the altered soil using the following formula: percent difference = ((| percent clay after alteration - percent clay before alteration |) / percent clay before alteration). For example, if the percent clay after alteration is 40 percent, and the percent clay before alteration is 70 percent, then $| 40 - 70 | = 30$, and $(30 / 70) = 43$ percent.

(6) Average the results from representative portions of the altered area.

(7) Multiply the percent difference for each altered area by the percent of the riverine wetland being assessed that the area represents (Column 3 in Table B6).

Table B6
Calculating Percent Difference of Clay in Soils of WAA

Area Description	Average Percent Difference in Clay Content in the Area	Percent of Area Being Assessed Occupied by the Area	Column 2 × Column 3
Altered Area 1	43% (0.43)	10% (0.10)	0.043
Altered Area 2	50% (0.50)	10% (0.10)	0.05
Unaltered Area	0.0% (0)	80% (0.80)	0
Percent difference = (sum of column 4) × 100 = 9.3 %			0.093

(8) Sum values in Column 4 and multiply by 100 to obtain the percent difference (last row in Table B6).

(9) Report the percent difference in the soil clay content in the area being assessed.

17. Redoximorphic features (V_{REDOX})

Measure/Units: The presence or absence of redoximorphic features is the measure of this variable.

Method: (1) Observe the top 30.5 cm (12 in.) of the soil profile and determine if redoximorphic features, accumulation or organic matter, or other hydric soil indicators are present or absent.

(2) Report redoximorphic features as present or absent.

18. Tree biomass (V_{TBA})

Measure/Units: Tree basal area in square meters per hectare is the measure of this variable.

Method: (1) Measure the dbh in centimeters of all trees in a circular 0.04-ha sampling unit (Pielou 1984), hereafter called a plot.

(2) Convert each of the diameter measurements to area, sum them, and then convert to square meters. For example, if 3 trees with diameters of 20 cm, 35 cm, and 22 cm were present in the plot, the conversion to square meters would be made as follows. Remembering that the diameter of a circle (D) can be converted to area (A) using the relationship $A = 1/4pD^2$, it follows that $1/4p20^2 = 314$ cm^2, $1/4p35^2 = 962$ cm^2, $1/4p22^2 = 380$ cm^2. Summing these values gives $314 + 962 + 380 = 1{,}656$ cm^2 and converting to square meters by

multiplying by 0.0001 gives 1,656 $cm^2 \times 0.0001 = 0.17\ m^2$. Not many trees in that plot!

(3) If multiple 0.04-ha plots are sampled, average the results from all plots.

(4) Convert the results to a per hectare basis by multiplying by 25, since there are 25 0.04-ha plots in a hectare. For example, if the average value from all the sampled plots is 0.17 m^2, then $1.7\ m^2 \times 25 = 4.3\ m^2/ha$.

(5) Report tree basal area in square meters per hectare.

19. Tree density (V_{TDEN})

Measure/Units: The number of tree stems per hectare.

Method: (1) Count the number of tree stems in a circular 0.04-ha plot.

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 20 stems, then $20 \times 25 =$ 500 stems/ha.

(4) Report tree density in stems/hectare.

20. Snag density (V_{SNAG})

Measure/Units: The number of snag stems per hectare.

Method: (1) Count the number of snag stems in a circular 0.04 plot.

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 2 stems, then $2 \times 25 = 50$ stems/ha.

(4) Report the number of snags as stems per hectare.

21. Woody debris biomass (V_{WD})

Measure/Units: Volume of woody debris in cubic meters per hectare is the measure of this variable.

Method: (1) Count the number of stems that intersect a vertical plane along a minimum of two transects located randomly and at least partially inside a 0.04-ha plot. Count the number of stems in each of three different size classes along the transect distance prescribed below. A 6-ft transect is used to count stems ≥0.25 to ≤1.0 in. in diameter, a 12-ft transect interval is used to count stems >1 to ≤3 in. in diameter, and a 50-ft transect is used to count stems >3 in. in diameter.

(2) Convert stem counts for each size class to tons per acre using the following formulas. For stems in the ≥0.25- to ≤1.0-in. and >1- to ≤3-in. size classes use the formula:

$$tons\,/\,acre = \frac{(11.64 \times n \times d^2 \times s \times a \times C)}{N \times l}$$

where

n = total number of intersections (i.e., counts) on all transects

d^2 = squared average diameter for each size class

s = specific gravity (Birdsey (1992) suggests a value of 0.58)

a = nonhorizontal angle correction (suggested value: 1.13)

C = slope correction factor (suggested valued: 1.0, since slopes in southeastern forested floodplains are negligible)

N = number of transects

l = total length of transects in feet

For stems in the >3-in. size class, use the following formula:

$$tons\,/\,acre = \frac{(11.64 \times \sum d^2 \times s \times a \times C)}{N \times l}$$

where

$\sum d^2$ = the sum of the squared diameter of each intersecting stem

When inventorying large areas with many different tree species, it is practical to use composite values and approximations for diameters, specific gravities, and nonhorizontal angle corrections. For example, if composite average diameters, composite average nonhorizontal correction factors, and best approximations for specific gravities are used for the Southeast, the preceding formula for stems in the 0.25-1.0 in. size class simplifies to:

$$tons / acre = (2.24 \times n) / (N \times l)$$

For stems in the >1.0- 3.0 in. size class, the formula simplifies to:

$$tons / acre = \frac{21.4(n)}{N \times l}$$

For stems in the >3.0 in. size class, the formula simplifies to:

$$tons / acre = \frac{6.87(\sum d^2)}{N \times l}$$

(3) Convert tons per acre to cubic feet per acre using the formula:

$$Cubic\ feet / acre = \frac{tons / acre \times 32.05}{0.58}$$

(4) Convert cubic feet per acre to cubic meters per hectare by multiplying by 0.072.

(5) Report woody debris volume in cubic meters per hectare.

22. Log biomass (V_{LOG})

Measure/Units: Volume of logs in cubic meters per hectare is the measure of this variable.

Method: (1) Use the volume of logs calculated for woody debris biomass (V_{WD}).

(2) Report log volume in cubic meters per hectare.

23. Understory vegetation biomass (V_{SSD})

Measure/Units: Stem density in number of stems per hectare.

Method: (1) Count the stems of understory vegetation in either a 0.04-ha plot, or each of four 0.004-ha sampling units, hereafter called subplots, located in representative portions of each quadrant of the 0.04-ha plot. Sample using four 0.004-ha subplots if the stand is in an early stage of succession and a high density of stems makes sampling 0.04-ha plots impractical.

(2) If 0.004-ha subplots are used, average the results to serve as the value for each 0.04-ha plot.

(3) If multiple 0.04-ha plots are sampled, average the results from all 0.04-ha plots.

(4) Convert the results to a per hectare basis by multiplying by 25. For example, if the average of the 0.04-ha plots is 23 stems, then $23 \times 25 = 575$ stems/ha.

(5) Report the number of understory vegetation stems as stems per hectare.

24. Ground vegetation biomass (V_{GVC})

Measure/Units: Percent cover of ground vegetation.

Methods: (1) Visually estimate the percentage of the ground surface that is covered by ground vegetation by mentally projecting the leaves and stems of ground vegetation to the ground surface in each of four 1-m^2 sampling units, hereafter called subplots, placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize an area will depend on its size and heterogeneity.

(2) Average the values from the four 1-m^2 subplots.

(3) If multiple 0.04-ha plots are sampled, average the results from these plots.

(4) Report ground vegetation cover as a percent.

25. "O" horizon biomass (V_{OHOR})

Measure/Units: Percent cover of the "O" horizon.

Method: (1) Visually estimate the percent of the ground surface that is covered by an "O" horizon in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

(2) Average the results from the subplots.

(3) If multiple 0.04-ha plots were sampled, average the results from these plots.

(4) Report "O" horizon cover as a percent.

26. "A" horizon biomass (V_{AHOR})

Measure/Units: Percent cover of the "A" horizon.

Method: (1) Estimate the percent of the mineral soil within the top 15 cm (6 in.) of the ground surface that qualifies as an "A" horizon by making a number of soil observations in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. For instance, if, in each subplot, 12 soil plugs are taken and 6 show the presence of a 7.5-cm- (3-in.-) thick "A" horizon, the value of "A" horizon cover is $(6 / 12) \times 100 = 50\%$. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

(2) Average the results from the 1-m^2 subplots.

(3) If multiple 0.04-ha plots were sampled, average the results from these plots.

(4) Report "A" horizon cover as a percent.

27. Plant species composition (V_{COMP})

Measure/Units: Percent concurrence with the dominant species in all vegetation strata.

Method: (1) Identify the dominant species in the canopy, understory vegetation, and ground vegetation strata using the 50/20 rule.[2] Use tree basal area to determine abundance in the canopy strata, understory vegetation density to determine abundance in the understory strata, and ground vegetation cover to determine abundance in the ground vegetation strata. To apply the 50/20 rule, rank species from each strata in descending order of abundance. Identify dominants by summing the normalized abundance measure beginning with the most abundant species in descending order until 50 percent is exceeded. Additional species with $\geq$20 percent normalized abundance are also considered as dominants. Accurate species identification is critical for determining the dominant species in each plot. Sampling during the dormant season may require a high degree of proficiency in identifying tree bark or dead plant parts. Users who do not feel confident in identifying plant species in all strata should get help with plant identification.

(2) For each vegetation strata, calculate percent concurrence by comparing the list of dominant plant species from each strata to the list of dominant species for each strata in reference standard wetlands in Table B7. For example, if all the dominants from the area being assessed occur on the list of dominants from reference standard wetlands, then there is 100 percent concurrence. If 3 of the 5 dominant species of trees from the area being assessed occur on the list, then there is 60 percent concurrence.

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[1] OCE Memorandum, 6 March 1992, Clarification of Use of the 1987 Delineation Manual.

(3) Average the percent concurrence from all three strata.

(4) Report percent concurrence with the dominant species in all vegetation strata.

Table B7
Dominant Species by Vegetation Strata by Zone in Reference Standard Sites in Western Tennessee

Zone	Tree	Shrub/Sapling	Ground Vegetation
Depression	*Nyssa aquatica*	*Carpinus caroliniana*	*Cornus foemina*
	Quercus lyrata	*Fraxinus pennsylvanica*	*Itea virginica*
	Taxodium distichum	*Nyssa aquatica*	*Saururus cernuus*
	Carya aquatica	*Quercus lyrata*	*Smilax rotundifolia*
		Itea virginica	*Peltandra virginica*
		Cornus foemina	
		Carya aquatica	
		Planera aquatica	
		Taxodium distichum	
Flat	*Carya glabra*	*Carpinus caroliniana*	*Arundinaria gigantea*
	Fraxinus pennsylvanica	*Carya glabra*	*Carex* spp.
	Liquidambar styraciflua	*Liquidambar styraciflua*	*Lobelia cardinalis*
	Quercus nigra	*Ulmus rubra*	*Smilax rotundifolia*
	Quercus michauxii	*Ulmus americana*	*Toxicodendron radicans*
	Quercus pagodaefolia	*Fraxinus pennsylvanica*	*Impatiens capensis*
	Quercus phellos	*Liquidambar styraciflua*	*Bignonia capreolata*
	Ulmus americana	*Quercus nigra*	*Boehmeria cylindrica*
		Quercus michauxii	*Aster simplex*
		Quercus pagodaefolia	*Vitis rotundifolia*
		Quercus phellos	*Vitis* spp.
Ridge	*Liquidambar styraciflua*	*Asimina triloba*	*Asimina triloba*
	Carya glabra	*Carpinus caroliniana*	*Arundinaria gigantea*
	Quercus alba	*Carya glabra*	*Boehmeria cylindrica*
	Quercus michauxii	*Carya ovata*	*Carex* spp.
	Quercus pagodaefolia	*Quercus nigra*	*Chasmanthium latifolium*
	Quercus phellos	*Ulmus americana*	*Toxicodendron radicans*
	Carya ovata	*Nyssa sylvatica*	*Bignonia capreolata*
	Quercus nigra	*Fagus grandifolia*	*Vitis rotundifolia*

(Continued)

Table B7 (Concluded)			
Zone	**Tree**	**Shrub/Sapling**	**Ground Vegetation**
Ridge (Continued)	*Ulmus americana*	*Quercus shumardii*	*Vitis* spp.
	Nyssa sylvatica	*Ulmus rubra*	*Smilax rotundifolia*
	Fagus grandifolia	*Liquidambar styraciflua*	*Onoclea sensibilis*
	Quercus shumardii	*Carya glabra*	
	Ulmus rubra	*Quercus alba*	
		Quercus michauxii	
		Quercus pagodaefolia	
		Quercus phellos	
Notes: Overlap of dominant species among zones may occur and is acceptable. Species listed in the tree and shrub/sapling layers also may occur in the ground vegetation layer, but were not listed because of space.			

Summary of Variables by Function

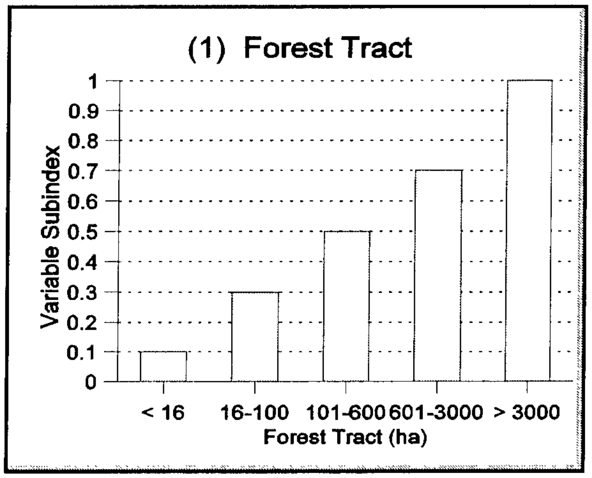
This section provides a listing of the model variables by function.

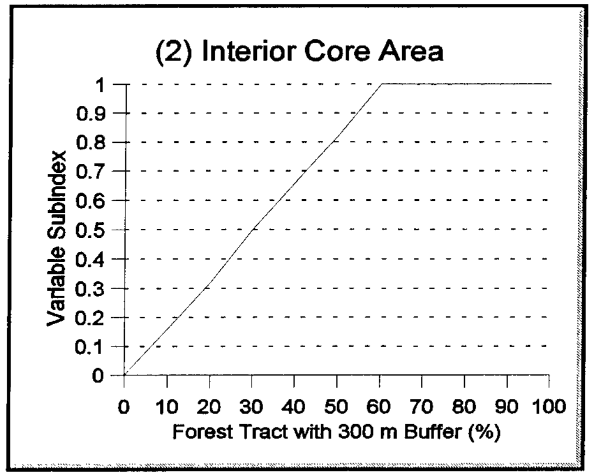
Variables	Function
1. Forest tract (V_{tract})	Provide habitat for wildlife
2. Interior core area (V_{core})	Provide habitat for wildlife
3. Habitat connections ($V_{connect}$)	Provide habitat for wildlife
4. Floodplain slope (V_{slope})	Temporarily store surface water Retain particulates
5. Floodplain storage volume (V_{store})	Temporarily store surface water Retain particulates
6. Macrotopographic features (V_{macro})	Provide habitat for wildlife
7. Overbank flood frequency (V_{freq})	Temporarily store surface water Remove and sequester elements and compounds Retain particulates Export organic carbon Maintain characteristic plant community Provide habitat for wildlife
8. Floodplain roughness (V_{rough})	Temporarily store surface water Retain particulates
9. Soil integrity ($V_{soilint}$)	Maintain characteristic plant community
10. Water table fluctuation (V_{wtf})	Maintain characteristic subsurface hydrology
	(Continued)

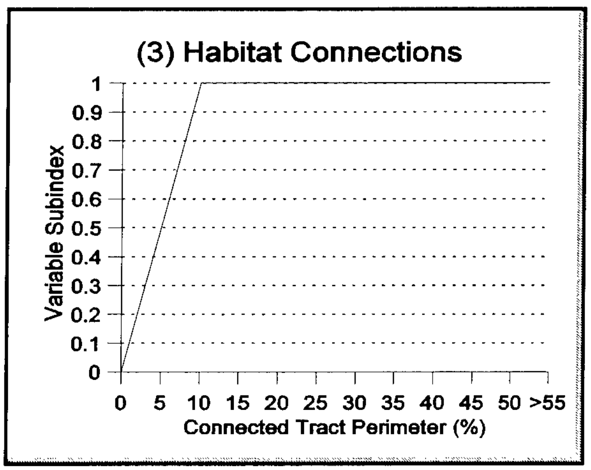
Variables	Function
11. Water table depth (V_{wtd})	Remove and sequester elements and compounds Maintain characteristic plant community
12. Water table slope ($V_{wtslope}$)	Maintain characteristic subsurface hydrology
13. Subsurface water velocity ($V_{soilperm}$)	Maintain characteristic subsurface hydrology
14. Subsurface storage volume (V_{pore})	Maintain characteristic subsurface hydrology
15. Surface water connections ($V_{surfcon}$)	Export organic carbon
16. Soil clay content (V_{clay})	Remove and sequester elements and compounds
17. Redoximorphic features (V_{redox})	Remove and sequester elements and compounds
18. Tree biomass (V_{tba})	Cycle nutrients Maintain characteristic plant community Provide habitat for wildlife
19. Tree density (V_{tden})	Maintain characteristic plant community Provide habitat for wildlife
20. Snag density (V_{snag})	Provide habitat for wildlife
21. Woody debris biomass (V_{wd})	Cycle nutrients Export organic carbon
22. Log biomass (V_{log})	Provide habitat for wildlife
23. Understory vegetation biomass (V_{sed})	Cycle nutrients
24. Ground vegetation biomass (V_{gvc})	Cycle nutrients
25. "O" horizon biomass (V_{ohor})	Cycle nutrients Remove and sequester elements and compounds Export organic carbon Provide habitat for wildlife
26. "A" horizon biomass (V_{ahor})	Cycle nutrients Remove and sequester elements and compounds
27. Plant species composition (V_{comp})	Maintain characteristic plant community Provide habitat for wildlife

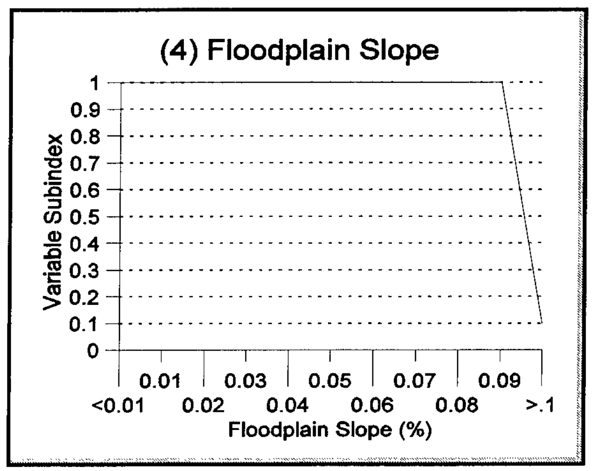
Summary of Graphs for Transforming Measures to Subindices in the Flats Zone

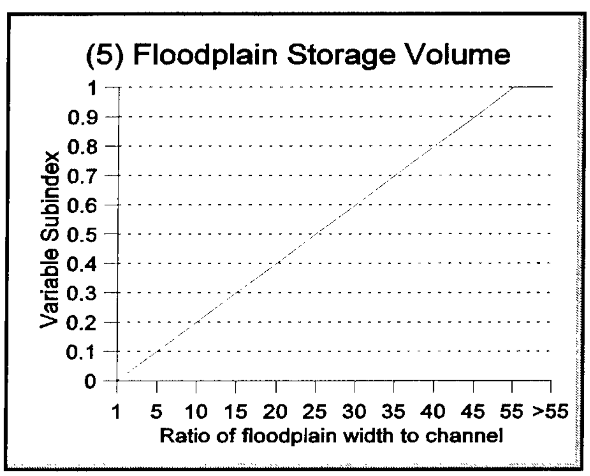
This section provides a summary of the graphical transformation of variable measures to variable subindices for the flats zone.

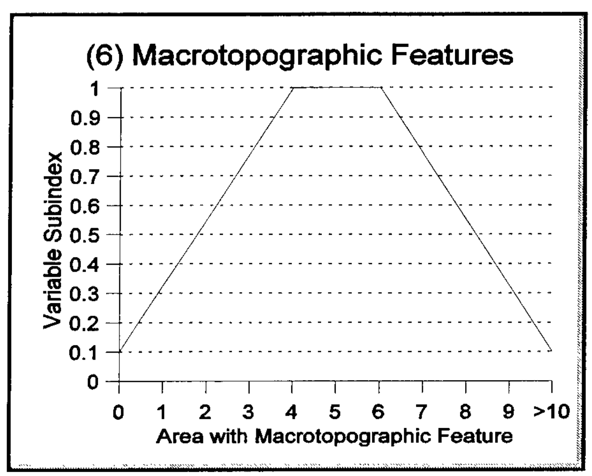


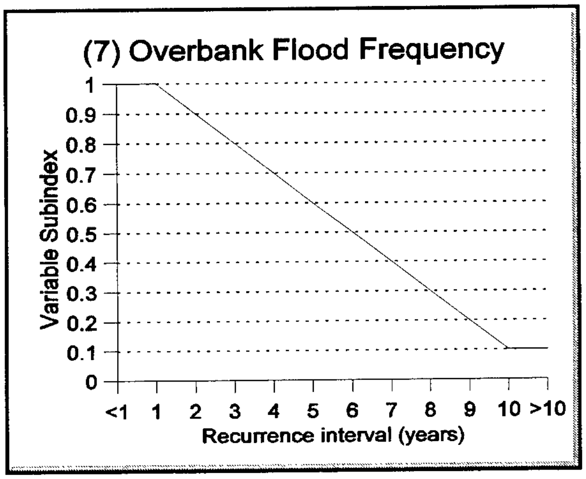


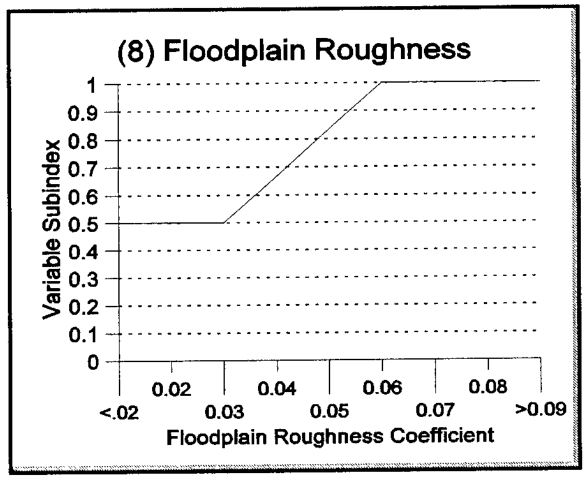


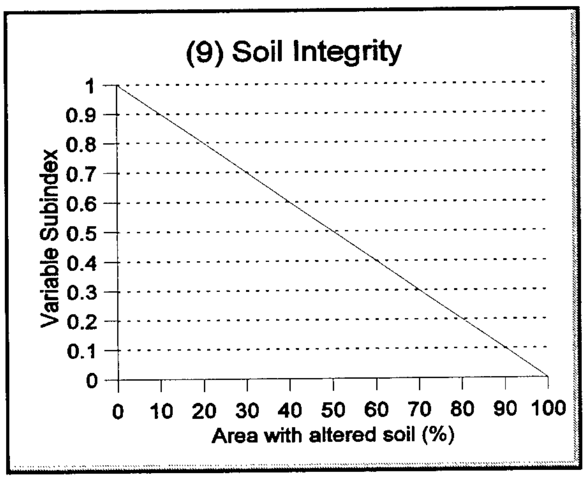


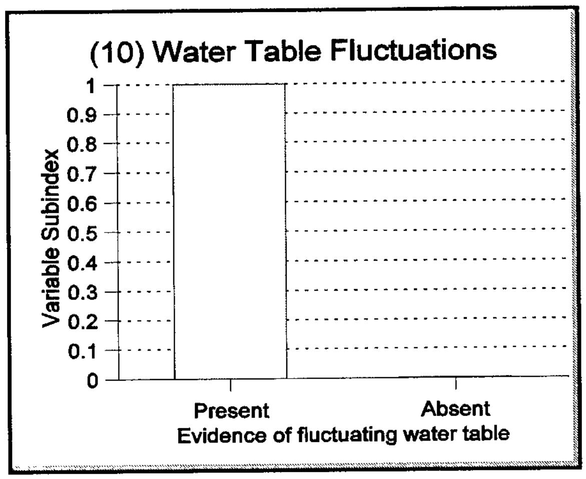


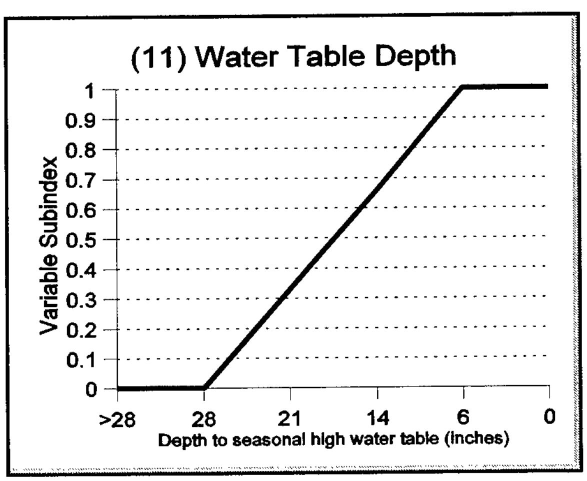


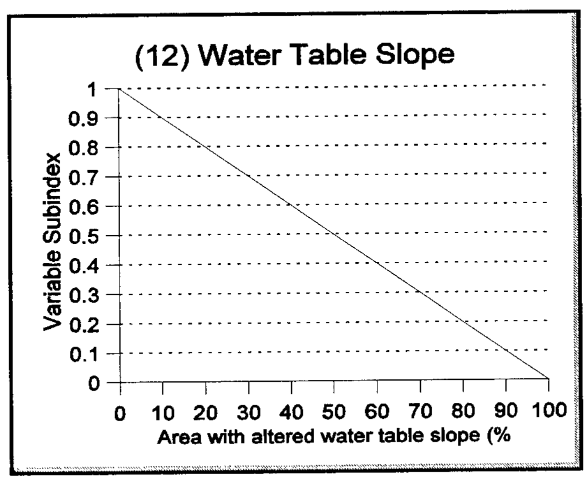

(7) Overbank Flood Frequency
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
<1 1 2 3 4 5 6 7 8 9 10 >10
Recurrence interval (years)

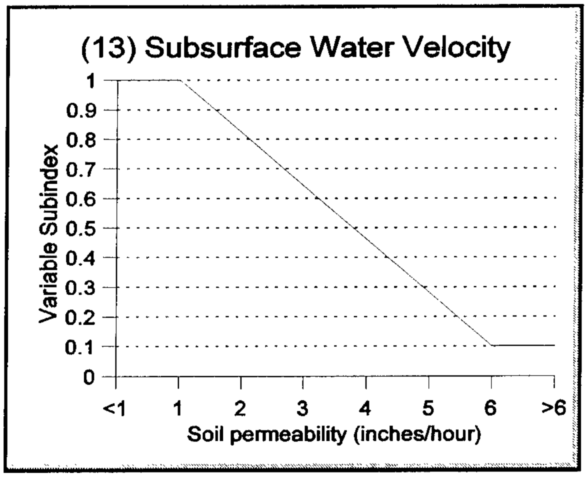

(8) Floodplain Roughness
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.02 0.04 0.06 0.08
<.02 0.03 0.05 0.07 >0.09
Floodplain Roughness Coefficient

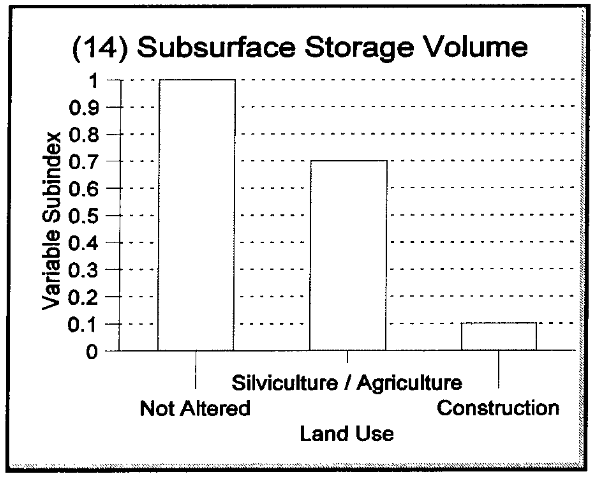

(9) Soil Integrity
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Area with altered soil (%)

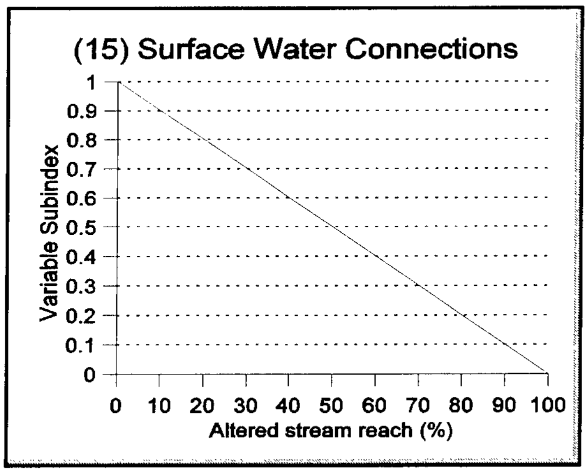

(10) Water Table Fluctuations
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Present
Absent
Evidence of fluctuating water table

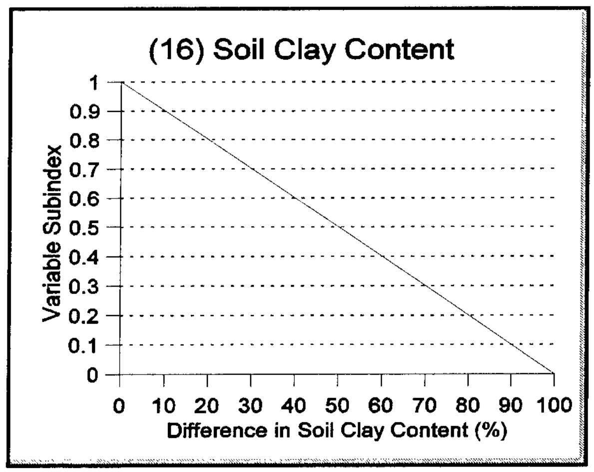

(11) Water Table Depth
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
>28 28 21 14 6 0
Depth to seasonal high water table (inches)

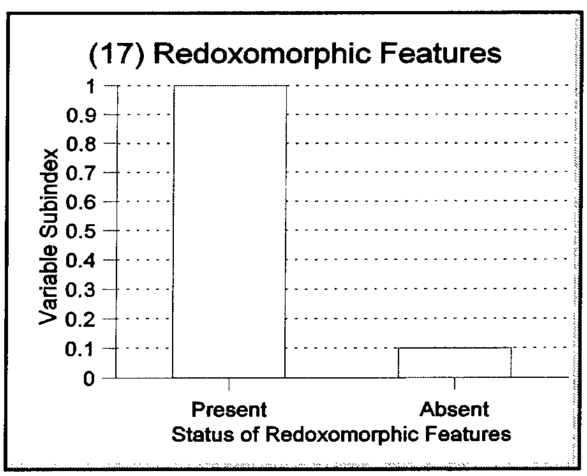

(12) Water Table Slope
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Area with altered water table slope (%

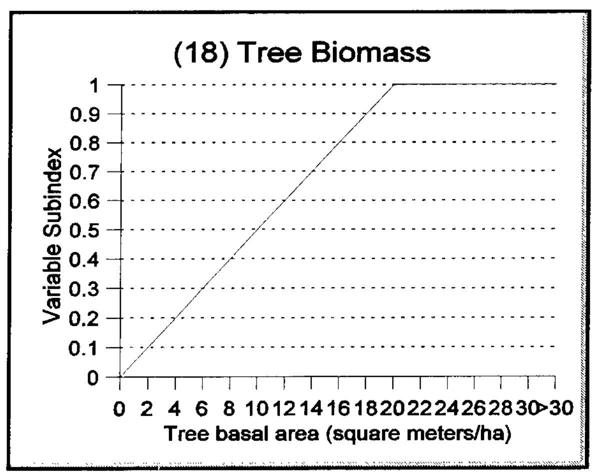

(13) Subsurface Water Velocity
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
<1
1
2
3
4
5
6
>6
Soil permeability (inches/hour)

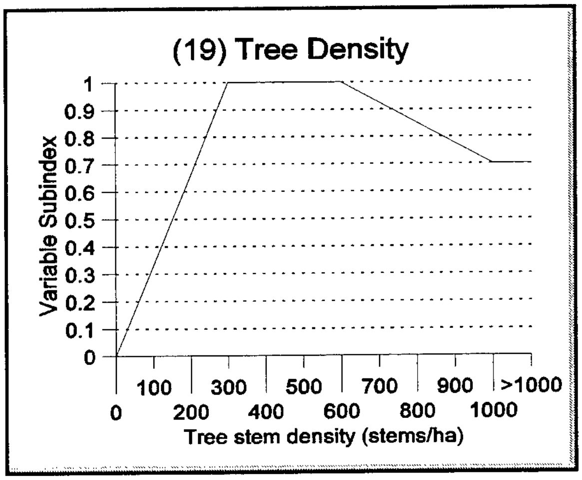

(14) Subsurface Storage Volume
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Not Altered
Silviculture / Agriculture
Construction
Land Use

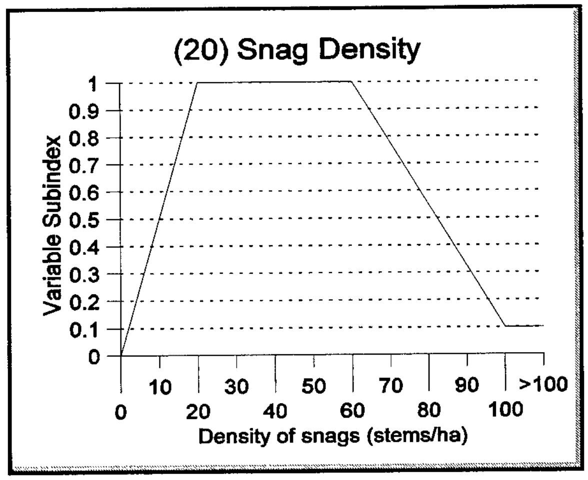

(15) Surface Water Connections
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Altered stream reach (%)

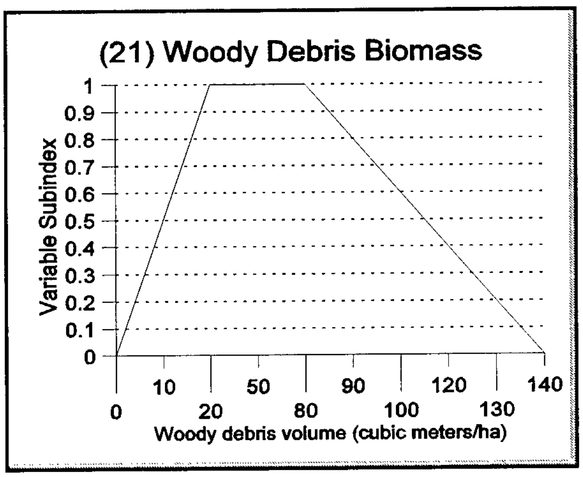

(16) Soil Clay Content
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Difference in Soil Clay Content (%)

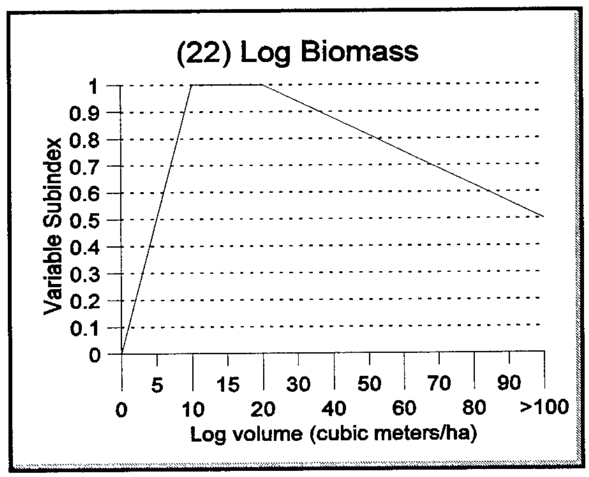

(17) Redoxomorphic Features
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Present
Absent
Status of Redoxomorphic Features

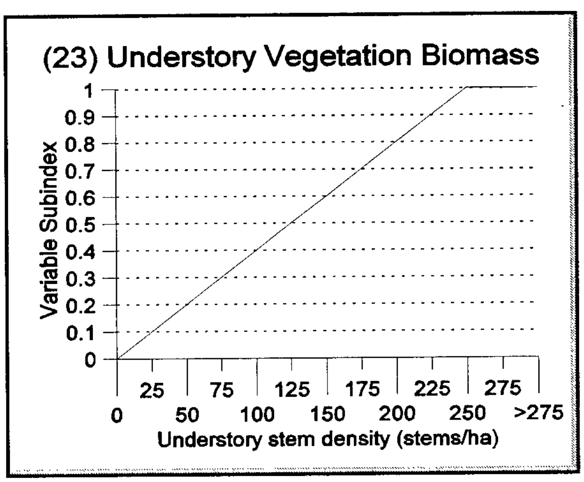

(18) Tree Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 >30
Tree basal area (square meters/ha)

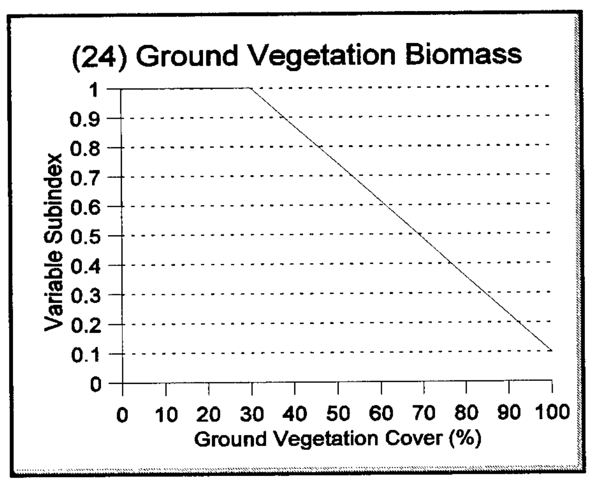

(19) Tree Density
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100 300 500 700 900 >1000
0 200 400 600 800 1000
Tree stem density (stems/ha)

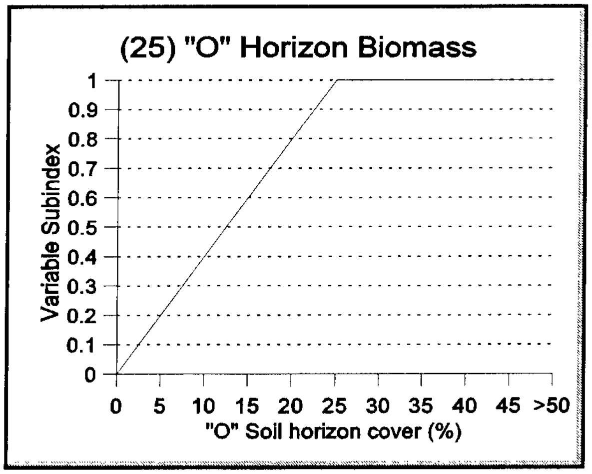

(20) Snag Density
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10 30 50 70 90 >100
0 20 40 60 80 100
Density of snags (stems/ha)


(21) Woody Debris Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10 50 90 120 140
0 20 80 100 130
Woody debris volume (cubic meters/ha)

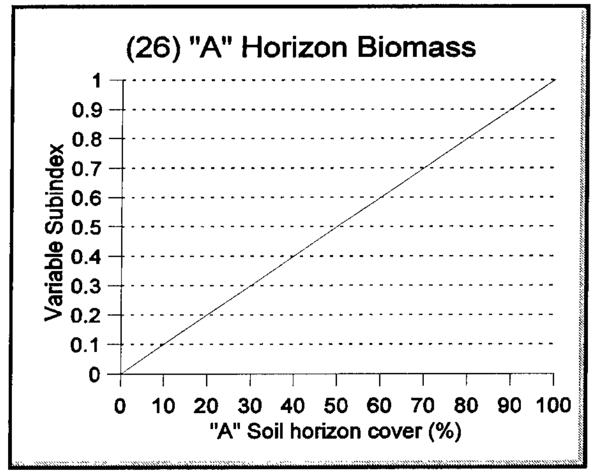

(22) Log Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 15 30 50 70 90
0 10 20 40 60 80 >100
Log volume (cubic meters/ha)


(23) Understory Vegetation Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
25 75 125 175 225 275
0 50 100 150 200 250 >275
Understory stem density (stems/ha)

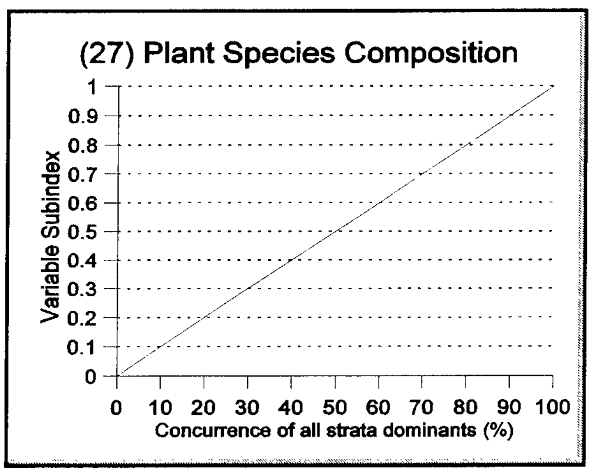

(24) Ground Vegetation Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Ground Vegetation Cover (%)



(25) "O" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 5 10 15 20 25 30 35 40 45 >50
"O" Soil horizon cover (%)



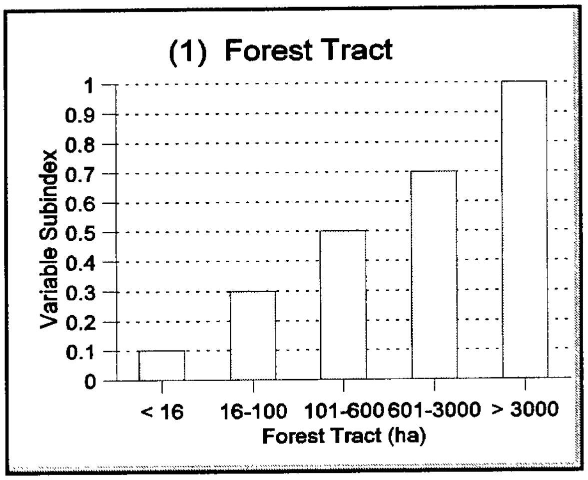
(26) "A" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
"A" Soil horizon cover (%)

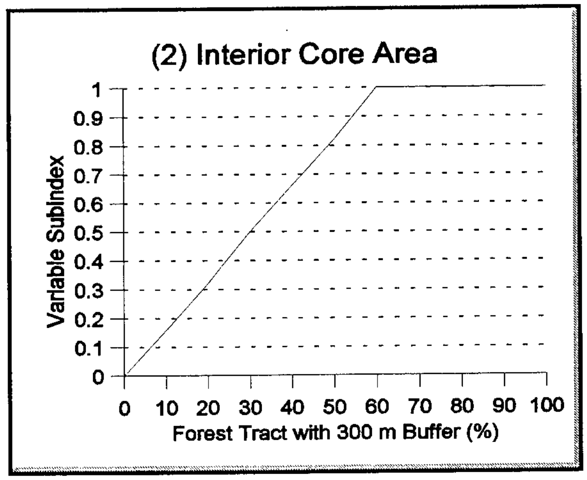


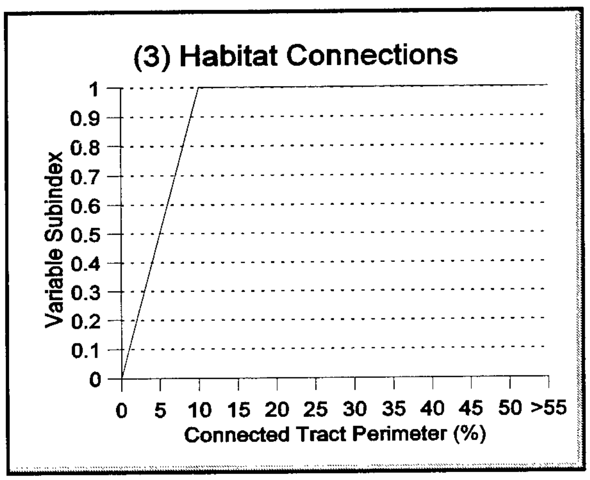
(27) Plant Species Composition
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Concurrence of all strata dominants (%)

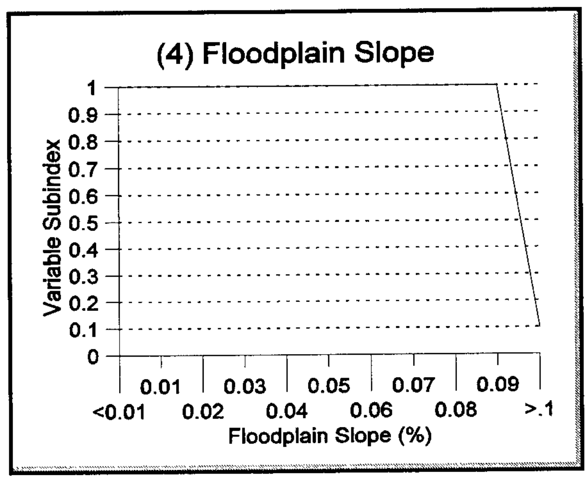
Summary of Graphs for Transforming Measures to Subindices in the Depression Zone

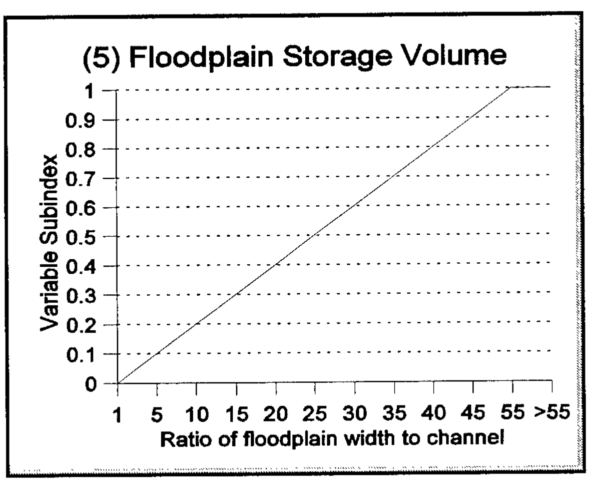
This section provides a summary of the graphical transformation of variable measures to variable subindices for the depression zone.

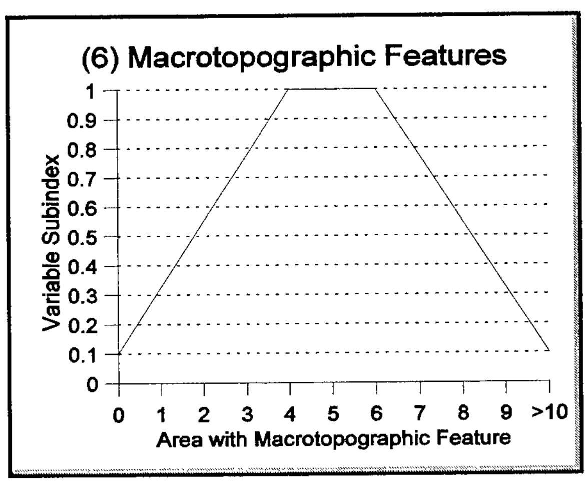


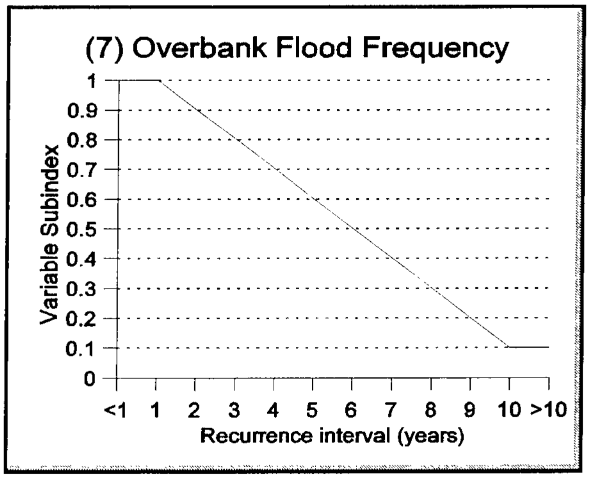


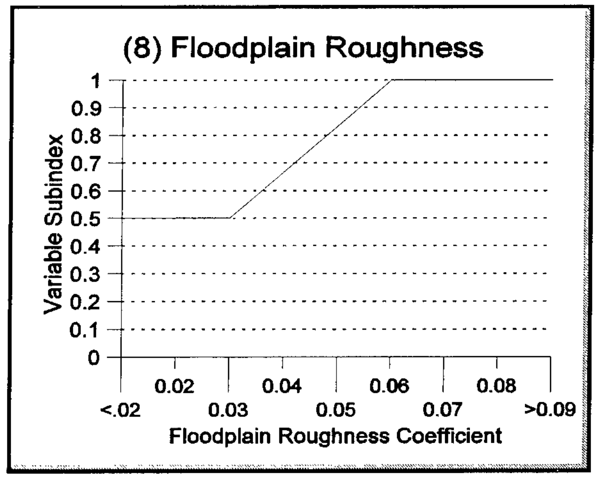


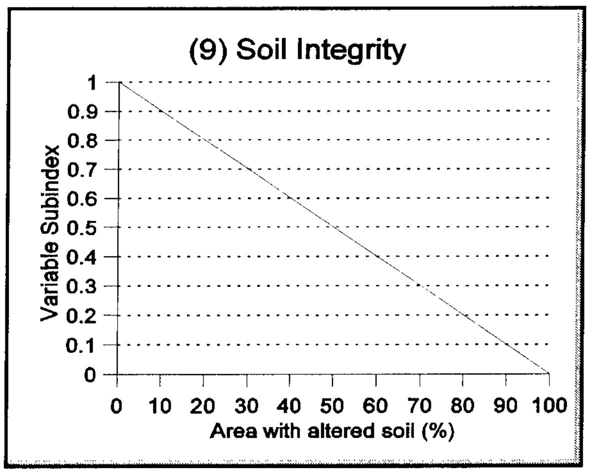


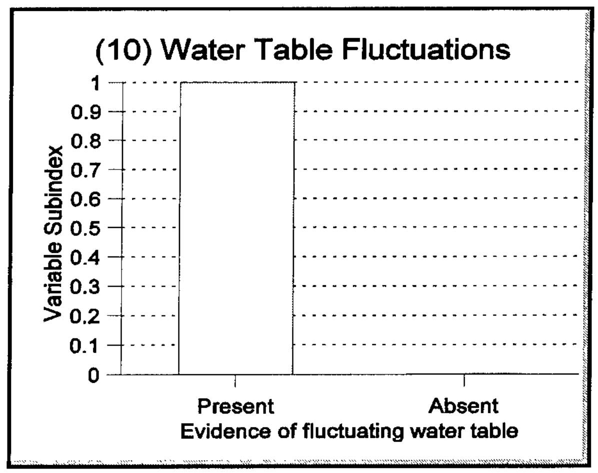


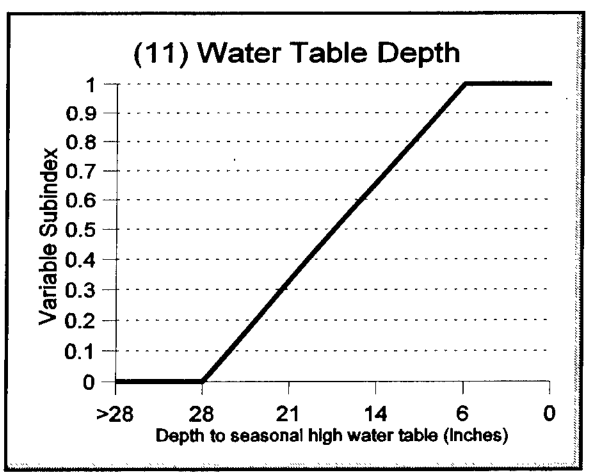


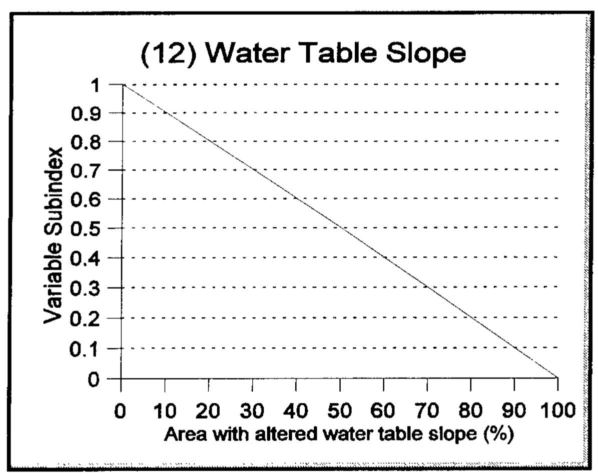

(7) Overbank Flood Frequency
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
<1 1 2 3 4 5 6 7 8 9 10 >10
Recurrence interval (years)

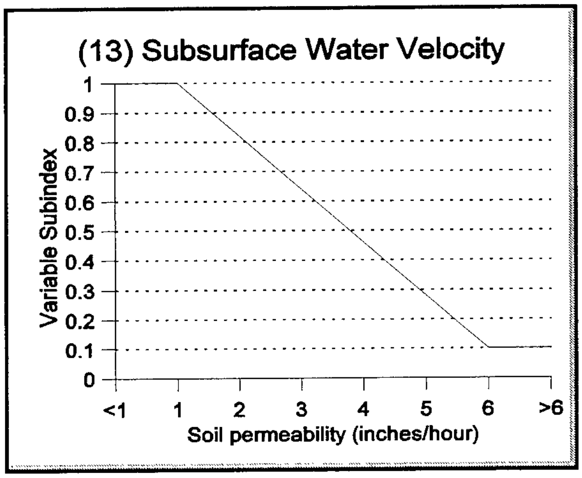

(8) Floodplain Roughness
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.02 0.04 0.06 0.08
<.02 0.03 0.05 0.07 >0.09
Floodplain Roughness Coefficient

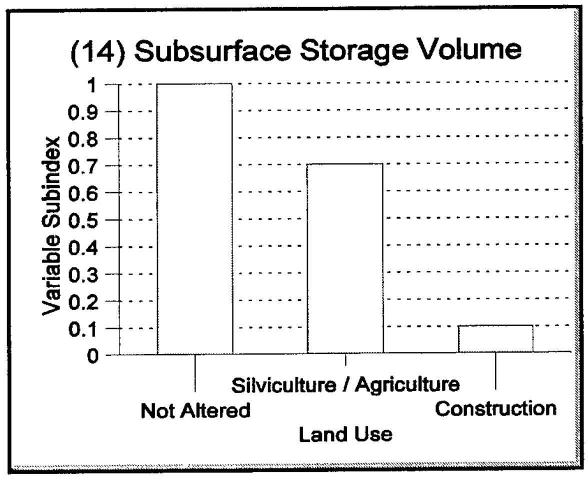

(9) Soil Integrity
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Area with altered soil (%)

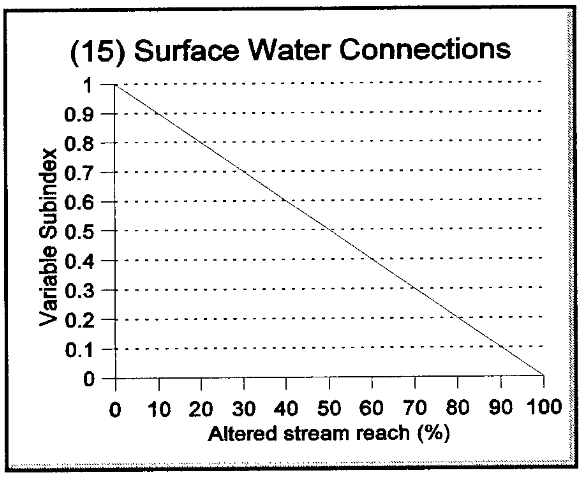

(10) Water Table Fluctuations
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Present
Absent
Evidence of fluctuating water table

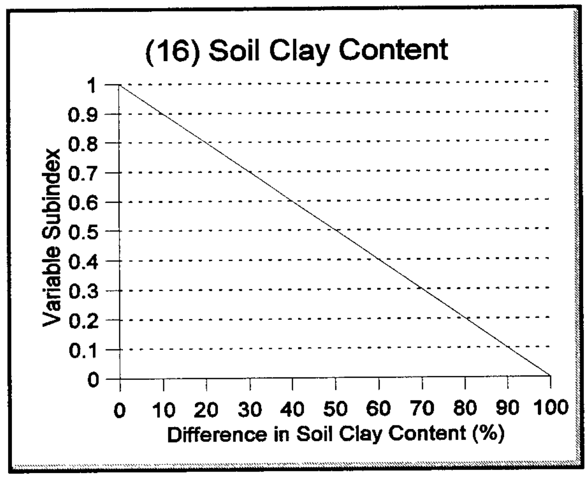

(11) Water Table Depth
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
>28 28 21 14 6 0
Depth to seasonal high water table (inches)

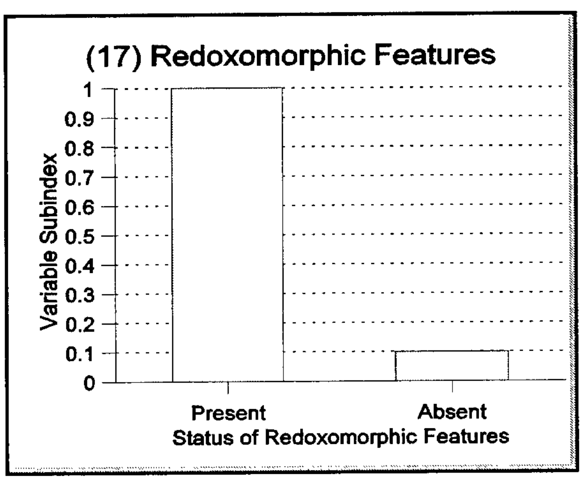

(12) Water Table Slope
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Area with altered water table slope (%)

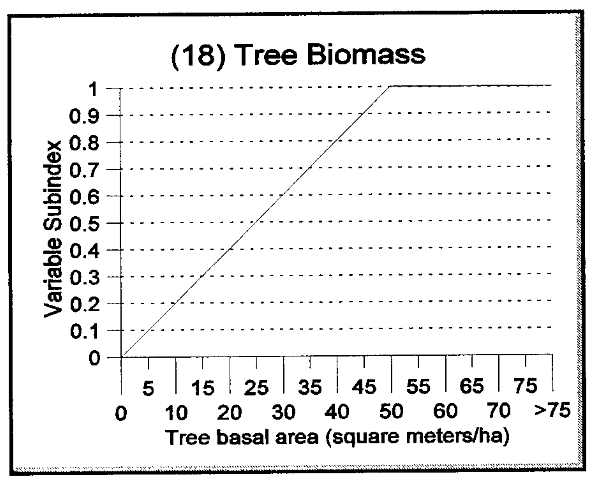

(13) Subsurface Water Velocity
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
<1
1
2
3
4
5
6
>6
Soil permeability (inches/hour)

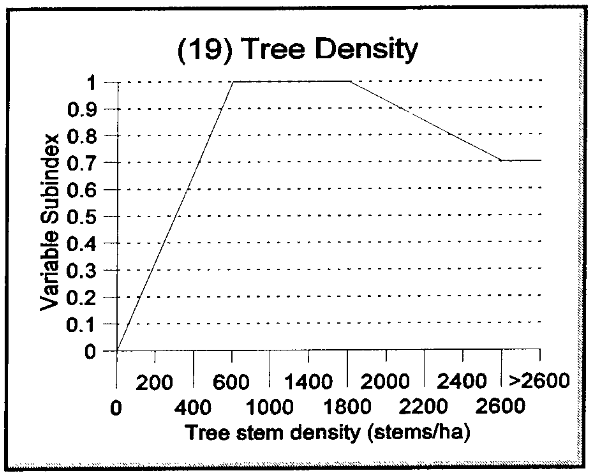

(14) Subsurface Storage Volume
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Not Altered
Silviculture / Agriculture
Construction
Land Use

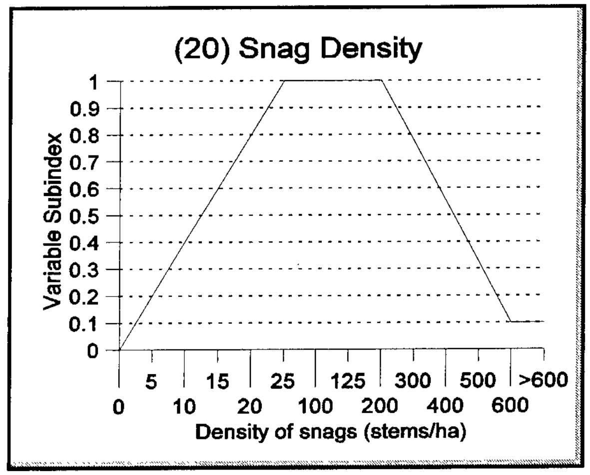

(15) Surface Water Connections
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Altered stream reach (%)

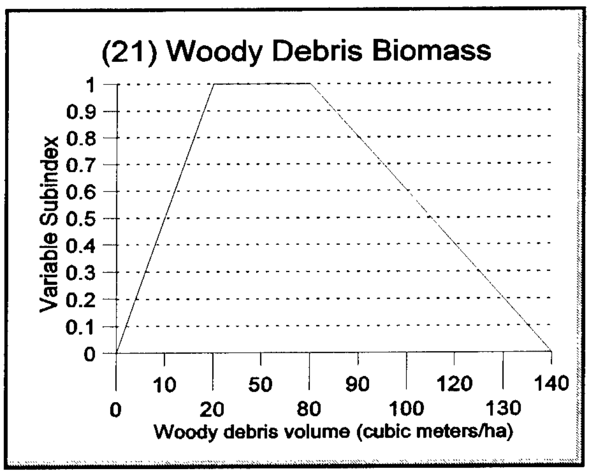

(16) Soil Clay Content
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Difference in Soil Clay Content (%)

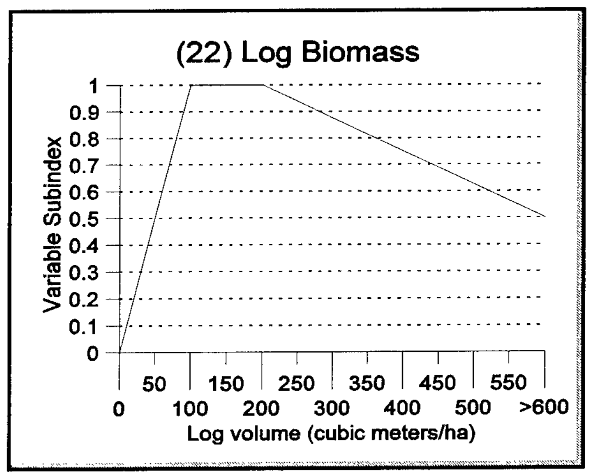

(17) Redoxomorphic Features
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Present
Absent
Status of Redoxomorphic Features

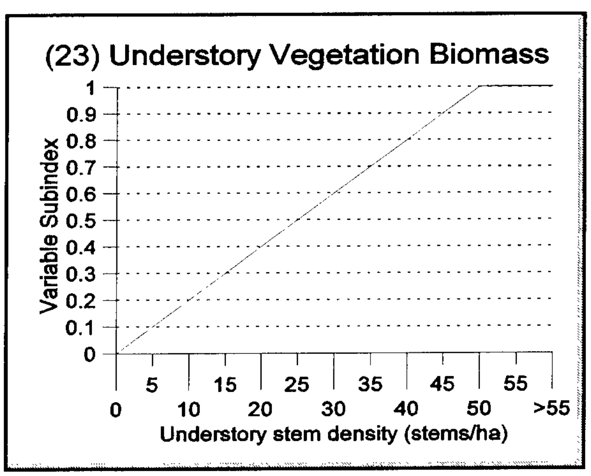

(18) Tree Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
15
25
35
45
55
65
75
0
10
20
30
40
50
60
70
>75
Tree basal area (square meters/ha)

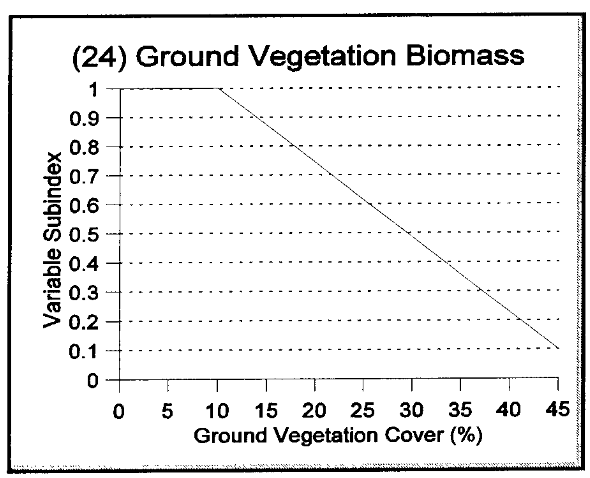

(19) Tree Density
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200 600 1400 2000 2400 >2600
0 400 1000 1800 2200 2600
Tree stem density (stems/ha)

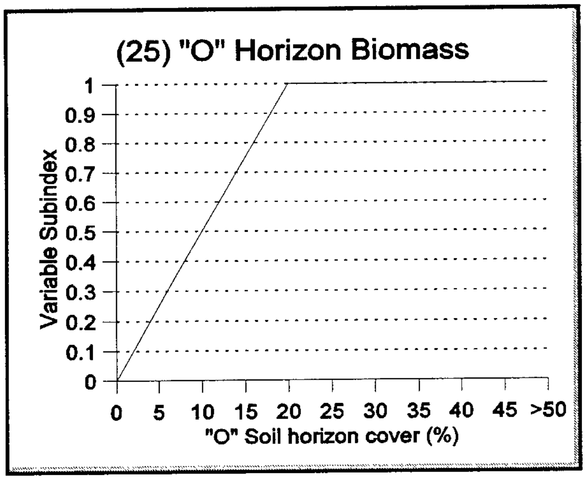

(20) Snag Density
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 15 25 125 300 500 >600
0 10 20 100 200 400 600
Density of snags (stems/ha)

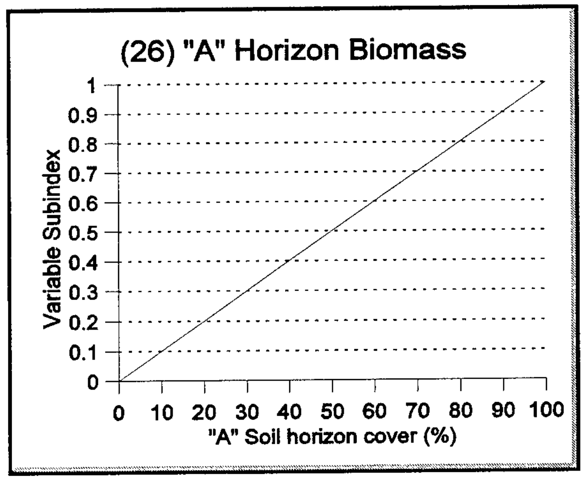

(21) Woody Debris Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10 50 90 120 140
0 20 80 100 130
Woody debris volume (cubic meters/ha)

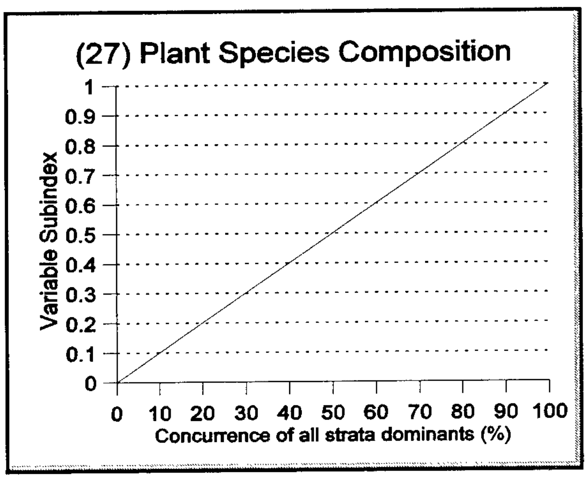

(22) Log Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50 150 250 350 450 550
0 100 200 300 400 500 >600
Log volume (cubic meters/ha)


(23) Understory Vegetation Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 15 25 35 45 55
0 10 20 30 40 50 >55
Understory stem density (stems/ha)


(24) Ground Vegetation Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 5 10 15 20 25 30 35 40 45
Ground Vegetation Cover (%)

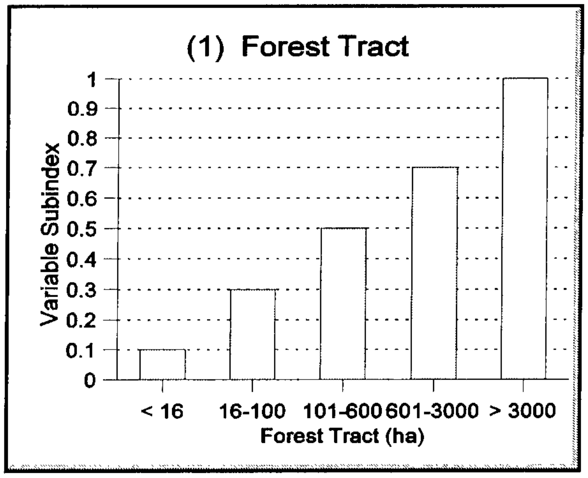

(25) "O" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 5 10 15 20 25 30 35 40 45 >50
"O" Soil horizon cover (%)

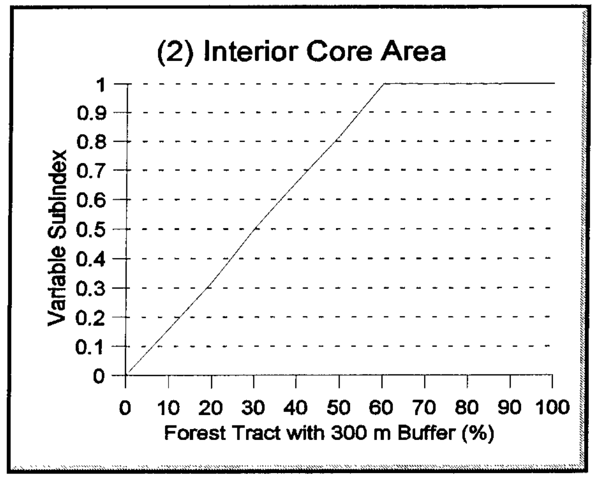

(26) "A" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
"A" Soil horizon cover (%)

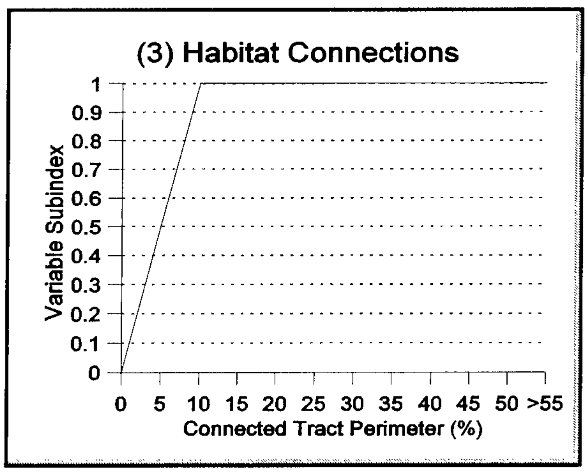

(27) Plant Species Composition
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Concurrence of all strata dominants (%)

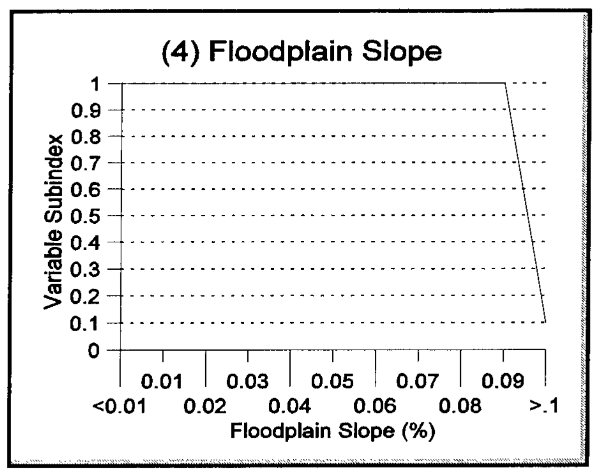
Summary of Graphs for Transforming Measures to Subindices in the Ridge Zone

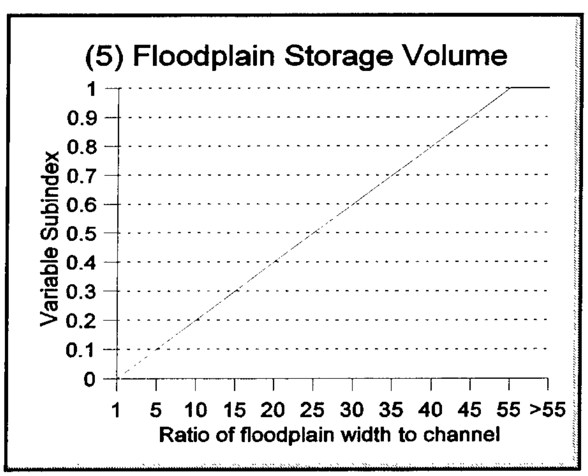
This section provides a summary of the graphical transformation of variable measures to variable subindices for the ridge zone.

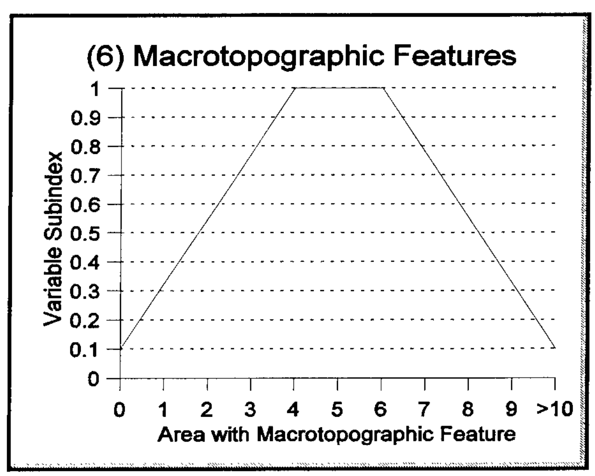


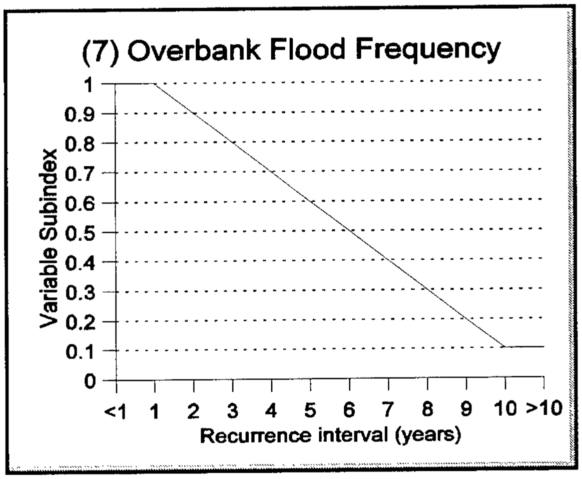


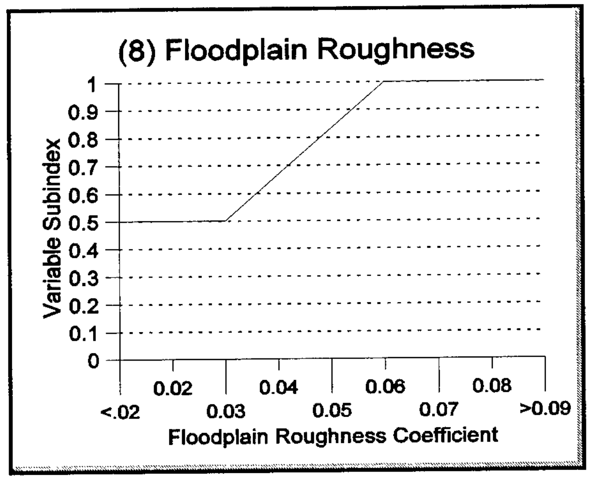


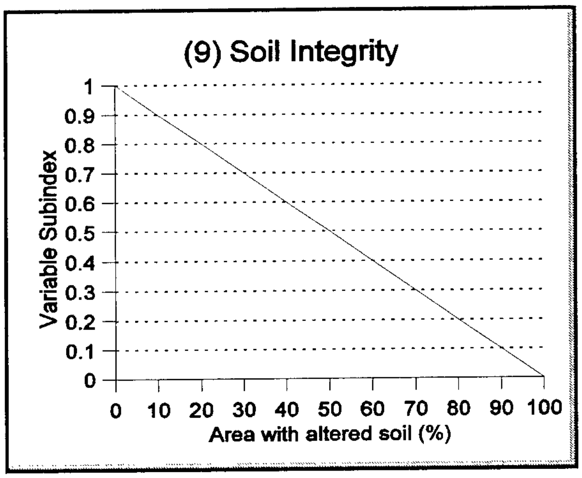


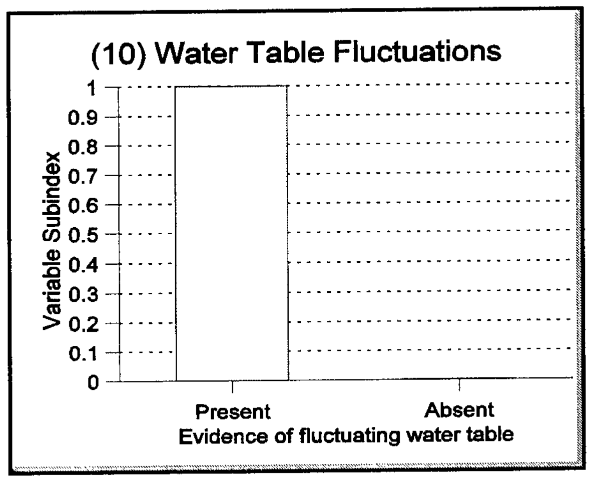


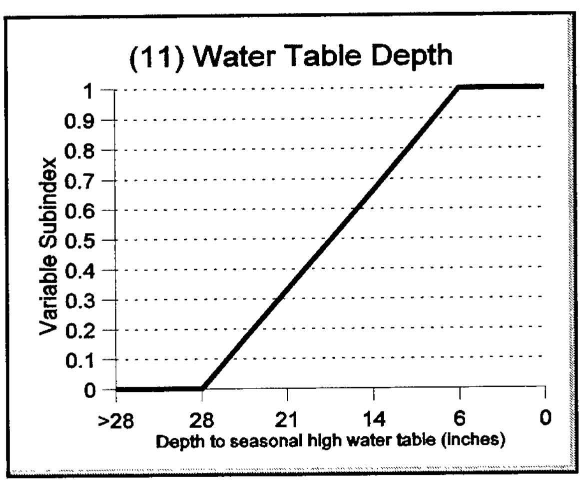


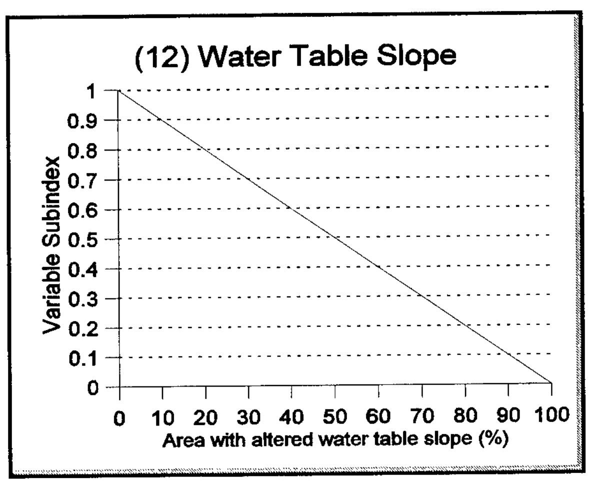

(7) Overbank Flood Frequency
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
<1 1 2 3 4 5 6 7 8 9 10 >10
Recurrence interval (years)

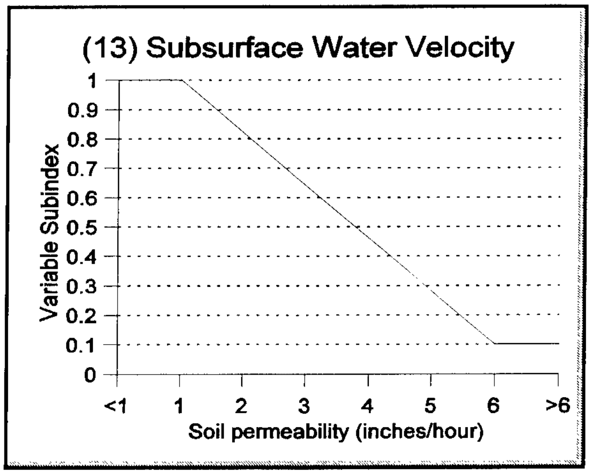

(8) Floodplain Roughness
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.02 0.04 0.06 0.08
<.02 0.03 0.05 0.07 >0.09
Floodplain Roughness Coefficient

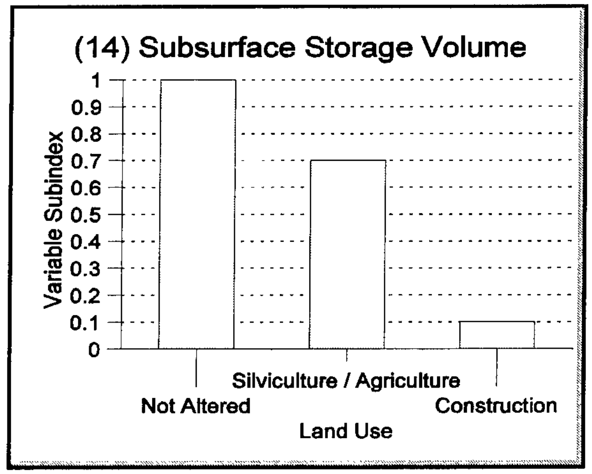

(9) Soil Integrity
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Area with altered soil (%)

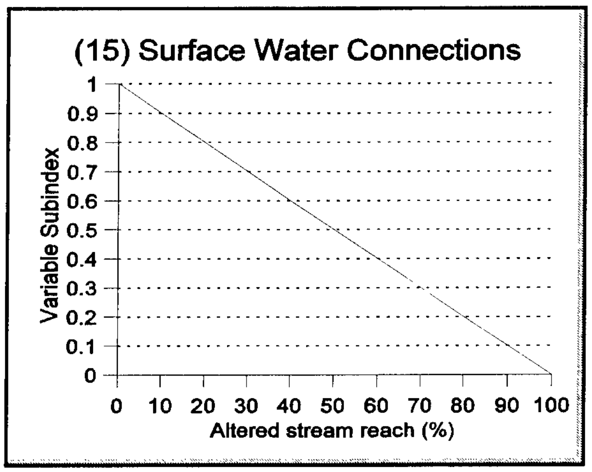

(10) Water Table Fluctuations
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Present
Absent
Evidence of fluctuating water table

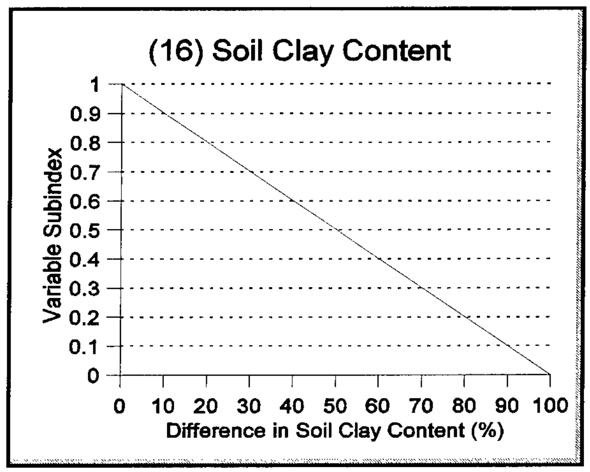

(11) Water Table Depth
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
>28 28 21 14 6 0
Depth to seasonal high water table (inches)

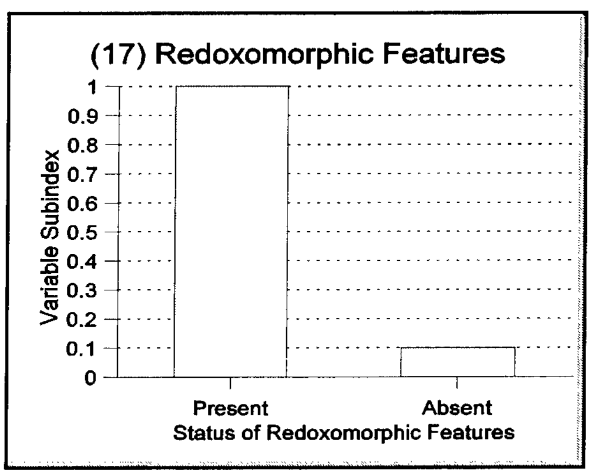

(12) Water Table Slope
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Area with altered water table slope (%)

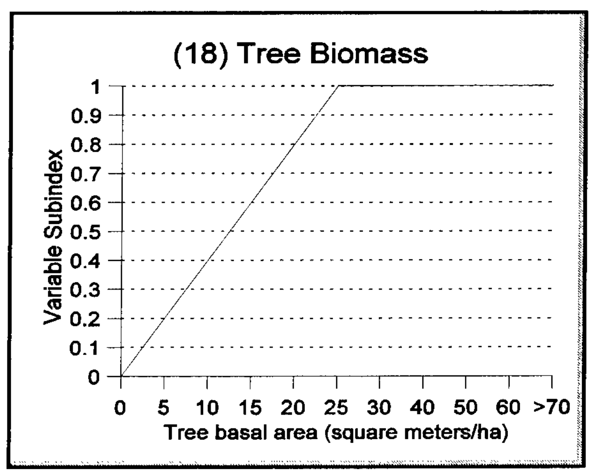

(13) Subsurface Water Velocity
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
<1
1
2
3
4
5
6
>6
Soil permeability (inches/hour)

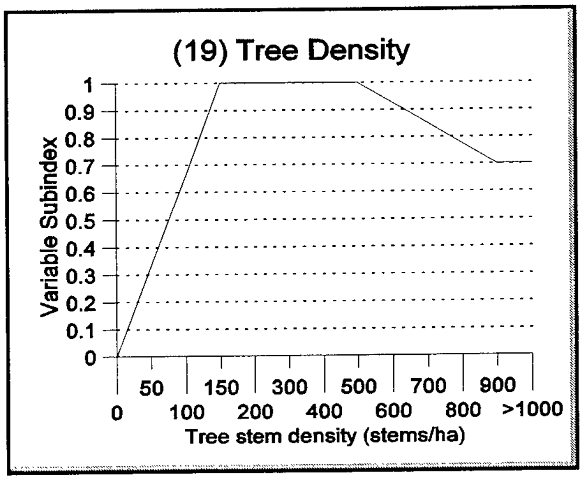

(14) Subsurface Storage Volume
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Silviculture / Agriculture
Not Altered
Construction
Land Use

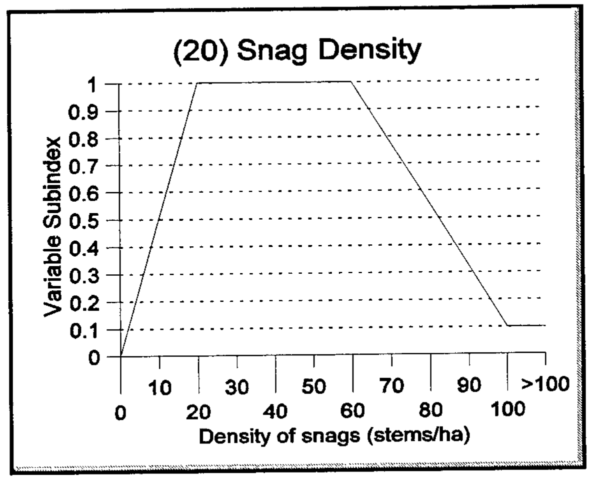

(15) Surface Water Connections
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Altered stream reach (%)

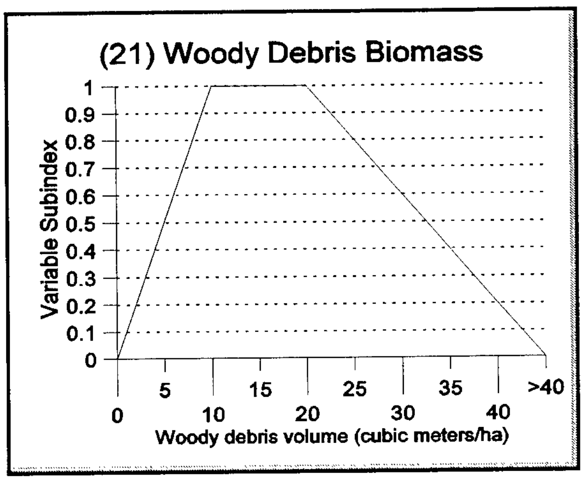

(16) Soil Clay Content
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Difference in Soil Clay Content (%)

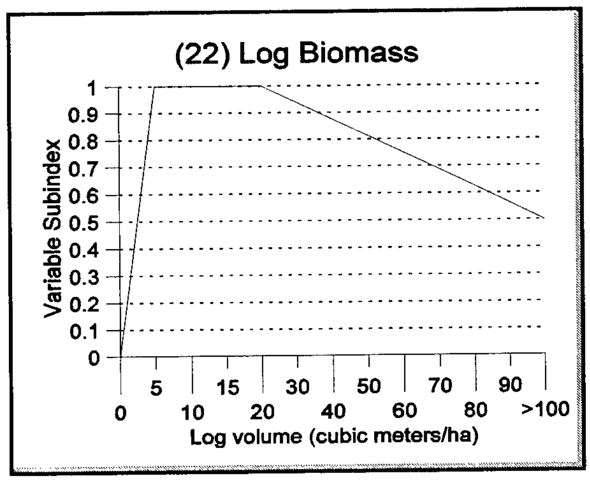

(17) Redoxomorphic Features
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Present
Absent
Status of Redoxomorphic Features

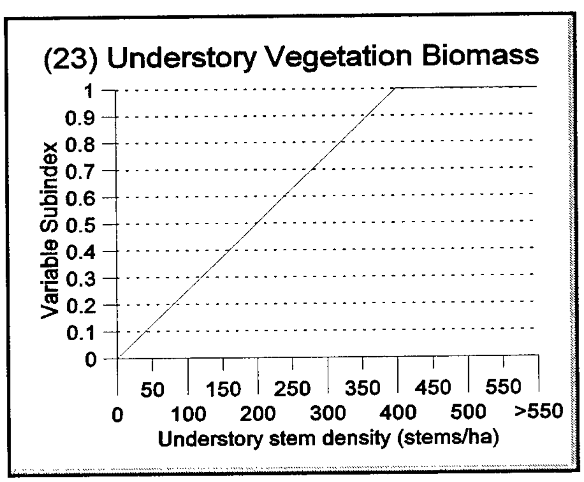

(18) Tree Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 5 10 15 20 25 30 40 50 60 >70
Tree basal area (square meters/ha)

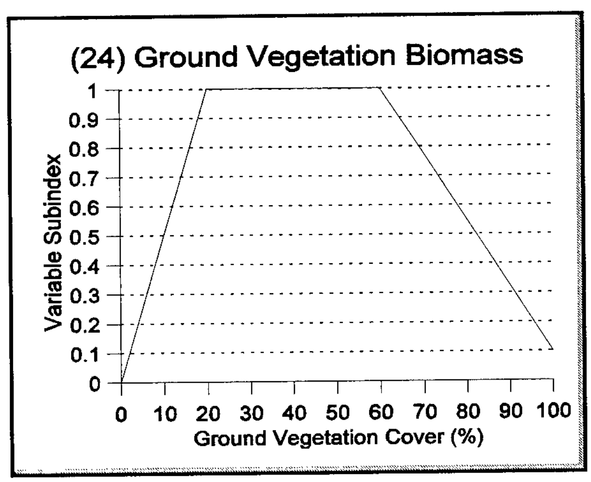

(19) Tree Density
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50 150 300 500 700 900
0 100 200 400 600 800 >1000
Tree stem density (stems/ha)

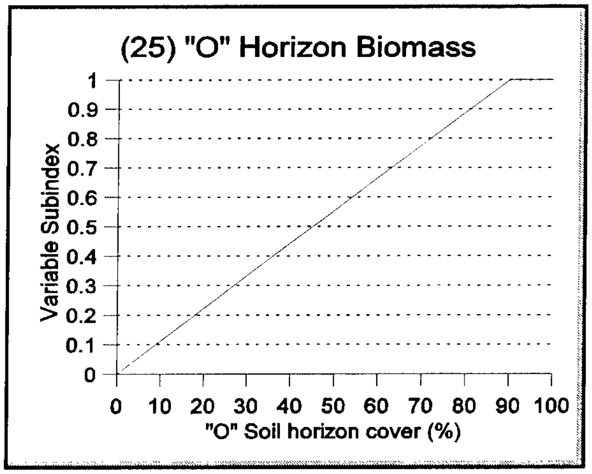

(20) Snag Density
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10 30 50 70 90 >100
0 20 40 60 80 100
Density of snags (stems/ha)

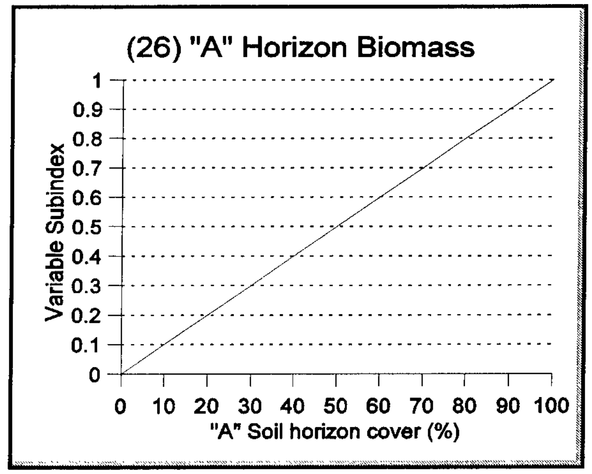

(21) Woody Debris Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 15 25 35 >40
0 10 20 30 40
Woody debris volume (cubic meters/ha)

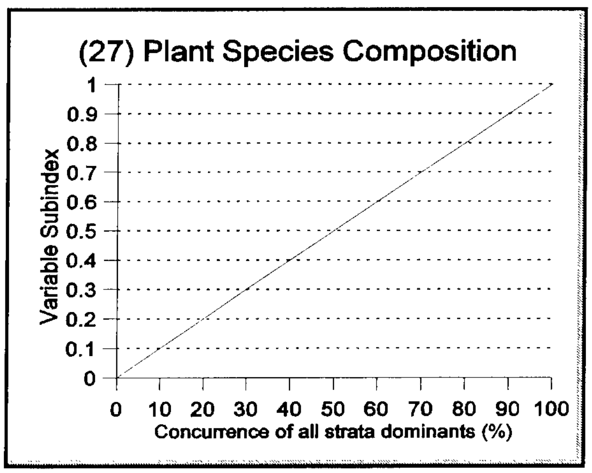

(22) Log Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 15 30 50 70 90
0 10 20 40 60 80 >100
Log volume (cubic meters/ha)


(23) Understory Vegetation Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50 150 250 350 450 550
0 100 200 300 400 500 >550
Understory stem density (stems/ha)


(24) Ground Vegetation Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Ground Vegetation Cover (%)


(25) "O" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
"O" Soil horizon cover (%)


(26) "A" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
"A" Soil horizon cover (%)


(27) Plant Species Composition
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Concurrence of all strata dominants (%)

Field Data Sheet: Low-Gradient Riverine Wetlands in Western Tennessee

Assessment Team: ______________________________
Project Name/Location: ______________________________
Date : ____________

Sample variables 1-6 using aerial photos, topographic maps, scenic overlooks, local informants, etc.

1. V_{TRACT} Area of the forest tract that is contiguous with the WAA . . . . _____ ha
2. V_{CORE} Percent of wetland tract that is >300 m from unsuitable habitat . . . . _____ %
3. $V_{CONNECT}$ Percent of wetland tract perimeter that is "connected" to suitable habitat . _____ %
4. V_{SLOPE} Percent floodplain slope . . . . _____ %
5. V_{STORE} Floodplain width to channel width ratio . . . . _____
6. V_{MACRO} Percent of WAA covered with macrotopographic features . . . . _____ %

Sample variables 7-17 based on a walking reconnaissance of the WAA

7. V_{FREQ} Overbank flood recurrence interval . . . . _____ years
   Check data source: gage data __, local knowledge __, flood frequency curves __, regional dimensionless curve __, hydrologic modeling __, other ___________ .
8. V_{ROUGH} Roughness Coefficient ___ (n_{BASE}) + ___ (n_{TOPO}) + ___ (n_{OBS}) + ___ (n_{VEG}) = _____
9. $V_{SOILINT}$ Percent of WAA with altered soils . . . . _____ %.
10. V_{WTF} Water table fluctuation is (check one): . . . . present _____ absent _____
    Check data source: groundwater well __ , redoximorphic features __ , County Soil Survey __.
11. V_{WTD} Water table depth is . . . . _____ inches
    Check data source: groundwater well __ , redoximorphic features __ , County Soil Survey __.
12. $V_{WTSLOPE}$ Percent of WAA with an altered water table slope . . . . _____ %
13. $V_{SOILPERM}$ Soil permeability . . . . _____ (in./hr)
14. V_{PORE} Percent effective soil porosity . . . . _____ %
15. $V_{SURFCON}$ Percent of adjacent stream reach with altered surface connections . . . _____ %
16. V_{CLAY} Percent of WAA with altered clay content in soil profile . . . . _____ %

17. V_{REDOX} Redoximorphic features are (check one): .... present _____ absent _____

Sample variables 18-20 from a representative number of locations in the WAA using a 0.04-ha circular plot (11.3-m (37-ft) radius)

18. V_{TBA} Tree basal area (average of 0.04-ha-plot values on next line) .... _____ m²/ha
0.04-ha plots: 1 ____ m²/ha 2 ____ m²/ha 3 ____ m²/ha 4 ____ m²/ha

19. V_{TDEN} Number of tree stems (average of 0.04 ha plot values on next line) _____ stems / ha
0.04-ha plots: 1 ____ stems/ha 2 ____ stems/ha 3 ____ stems/ha
4 ____ stems/ha

20. V_{SNAG} Number of snags (average of 0.04-ha-plot values on next line) ... _____ stems / ha
0.04-ha plots: 1 ____ stems/ha 2 ____ stems/ha 3 ____ stems/ha
4 ____ stems/ha

Sample variables 21-22 on two (2) 15-m transects partially within the 0.04-ha plot

21. V_{WD} Volume of woody debris (average of transect values on next line) .... _____ m³/ha
Transect: 1 ____ m³/ha 2 ____ m³/ha 3 ____ m³/ha 4 ____ m³/ha

22. V_{LOG} Volume of logs (average of transect values on next line) .... _____ m³/ha
Transect: 1 ____ m³/ha 2 ____ m³/ha 3 ____ m³/ha 4 ____ m³/ha

Sample variable 23 in two (2) 0.004-ha circular subplots (3.6-m (11.8-ft) radius) placed in representative locations of the 0.04-ha plot

23. V_{SSD} Number of woody understory stems (average of 0.04 ha plot values on next line)
.... _____ stems / ha
0.04-ha plots: 1 ____ stems/ha 2 ____ stem/ha 3 ____ stems/ha
4 ____ stems/ha

Sample variables 24-27 in four (4) m² subplots placed in representative locations of each quadrant of the 0.04-ha plot

24. V_{GVC} Average cover of ground vegetation (average of 0.04-ha-plot values on next line)
.... _____ %
Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %

25. V_{OHOR} Average cover of "O" Horizon (average of 0.04-ha-plot values on next line)_____ %
Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %

26. V_{AHOR} Average cover of "A" Horizon (average of 0.04-ha-plot values on next line)_____ %
Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %

27. V_{COMP} Concurrence with all strata dominants (average of 0.04-ha-plot values on next line)
.... _____ %
Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %

Plot Worksheet: Low-Gradient Riverine Wetlands in Western Tennessee

Assessment Team : ______________________________

Project Name/Location : ______________________ **Plot Number :** _____

Date : ________

Record dbh (cm) of trees by species below, square dbh values (cm^2), multiply result by 0.000079 (m^2), and sum resulting values in shaded columns (m^2/0.04 ha). Record in 18. V_{TBA}, multiply by 25 (m^2/ha).

Species	dbh (cm)	dbh^2 (cm^2)	× 0.000079 (m^2/0.04 ha)	Species	dbh (cm)	dbh^2 (cm^2)	× 0.000079 (m^2/0.04 ha)

18. V_{TBA} Sum of values from shaded columns above = ______ (m^2/0.04 ha) × 25 = _________ m^2/ha

19. V_{TDEN} Total number of tree stems from above = _______ (stems/0.04 ha) × 25 = ________ stems/ha

20. V_{SNAG} Total number of snag stems from above= _____ (stems/0.04 ha) × 25 = _________ stems/ha

21/22. V_{WD}/V_{LOG}

Record number of stems in Size Class 1 (0.6-2.5 cm (0.25-1 in.)) along a 6-ft section of Transect 1 and 2

Transect 1 _______ Transect 2 _______ *Total number of stems* = _______

Size Class 1 tons /acre = 0.187 × *total number of stems* = ... _____ tons/acre

Record number of stems in Size Class 2 (2.5 - 7.6 cm (1-3 in.)) along 12-ft section of Transect 1 and 2

Transect 1_______ Transect 2 _______ *Total number of stems* = _______

Size Class 2 tons / acre = 0.892 × *total number of stems* = ... _____ tons/acre

Record diameter of stems in Size Class 3 (> 7.6 cm (>3 in.)) along 50-ft section of Transect 1 and 2

Transect 1	diameter	$diameter^2$	Transect 2	diameter	$diameter^2$
Stem 1 =	_____	_____	Stem 1 =	_____	_____
Stem 2 =	_____	_____	Stem 2 =	_____	_____
Stem 3 =	_____	_____	Stem 3 =	_____	_____
Stem 4 =	_____	_____	Stem 4 =	_____	_____
Total $diameter^2$		_____	Total diameter ^{2}		_____

Total diameter² of stems from both transects = _____

Size Class 3 tons/acre = 0.0687 × *Total diameter ² of stems from both transects* =
. . . . _____ tons/acre

Total tons/acre (sum of Size Classes 1-3 from above) = ... _____ tons/acre

Cubic feet/acre = (32.05 × *total tons/acre*)/0.58 = ... _____cubic feet/acre

Cubic meters/ha = *cubic feet/acre* × 0.069 . . . . _____ cubic meters/ha

23. V_{SSD} Tally woody understory stems two 0.004-ha subplots, then average and multiply by 250:
Subplot 1 ______ Subplot 2 ______ Average ____ × 250 = ... _____ stems/ha

24. V_{GVC} Estimate percent cover of ground vegetation in four m^2 subplots, then average:
1 ____ % 2 ____ % 3 ____ % 4 ____ % . . . . Average _____ %

25. V_{OHOR} Estimate percent cover of "O" Horizon in four m^2 subplots, then average:
1 ____ % 2 ____ % 3 ____ % 4 ____ % . . . . Average _____ %

26. V_{AHOR} Estimate percent cover of "A" Horizon in four m^2 subplots, then average:
1 ____ % 2 ____ % 3 ____ % 4 ____ % . . . . Average _____ %

27. V_{COMP} Determine percent concurrence with each strata using the table below
Tree = __ % Shrub/Sapling = __ % Ground Vegetation = __ % . . Average ___ %

Dominant Species by Vegetation Strata by Zone in Reference Standard Sites in Western Tennessee

Zone	Tree	Shrub/Sapling	Ground Vegetation
Depression	*Nyssa aquatica*	*Carpinus caroliniana*	*Cornus foemina*
	Quercus lyrata	*Fraxinus pennsylvanica*	*Itea virginica*
	Taxodium distichum	*Nyssa aquatica*	*Saururus cernuus*
	Carya aquatica	*Quercus lyrata*	*Smilax rotundifolia*
		Itea virginica	*Peltandra virginica*
		Cornus foemina	
		Carya aquatica	
		Planera aquatica	
		Taxodium distichum	
Flat	*Carya glabra*	*Carpinus caroliniana*	*Arundinaria gigantea*
	Fraxinus pennsylvanica	*Carya glabra*	*Carex* spp.
	Liquidambar styraciflua	*Liquidambar styraciflua*	*Lobelia cardinalis*
	Quercus nigra	*Ulmus rubra*	*Smilax rotundifolia*
	Quercus michauxii	*Ulmus americana*	*Toxicodendron radicans*
	Quercus pagodaefolia	*Fraxinus pennsylvanica*	*Impatiens capensis*
	Quercus phellos	*Liquidambar styraciflua*	*Bignonia capreolata*
	Ulmus americana	*Quercus nigra*	*Boehmeria cylindrica*
		Quercus michauxii	*Aster simplex*
		Quercus pagodaefolia	*Vitis rotundifolia*
		Quercus phellos	*Vitis* spp.
Ridge	*Liquidambar styraciflua*	*Asimina triloba*	*Asimina triloba*
	Carya glabra	*Carpinus caroliniana*	*Arundinaria gigantea*
	Quercus alba	*Carya glabra*	*Boehmeria cylindrica*
	Quercus michauxii	*Carya ovata*	*Carex* spp.
	Quercus pagodaefolia	*Quercus nigra*	*Chasmanthium latifolium*
	Quercus phellos	*Ulmus americana*	*Toxicodendron radicans*
	Carya ovata	*Nyssa sylvatica*	*Bignonia capreolata*
	Quercus nigra	*Fagus grandifolia*	*Vitis rotundifolia*
	Ulmus americana	*Quercus shumardii*	*Vitis* spp.
	Nyssa sylvatica	*Ulmus rubra*	*Smilax rotundifolia*

(Continued)

Zone	Tree	Shrub/Sapling	Ground Vegetation
Ridge (Continued)	*Fagus grandifolia*	*Liquidambar styraciflua*	*Onoclea sensibilis*
	Quercus shumardii	*Carya glabra*	
	Ulmus rubra	*Quercus alba*	
		Quercus michauxii	
		Quercus pagodaefolia	
		Quercus phellos	

Notes:
Overlap of dominant species among zones may occur and is acceptable.
Species listed in the tree and shrub/sapling layers also may occur in the ground vegetation layer, but were not listed because of space.

Appendix C
Supplementary Information on Model Variables

This appendix contains the following summaries:

a. van Schilfgaarde Equation - page C2

b. Effective Soil Porosity - page C4

c. Soil Texture by Feel - page C5

d. Pumping Test - page C7

e. Flood Frequency Analysis Methods - page C8

van Schilfgaarde Equation

The van Schilfgaarde equation was originally developed to approximate the spacing and depth of ditches for agriculture (Figure C1). It is currently being used to determine hydrologic alteration in the context of crop production where the usual requirement is to lower the water table below the root zone within 24 to 48 hr after saturation (USDA NRCS 1996).[1] The objective of utilizing the van Schilfgaarde equation in this Regional Guidebook is to assess the extent that a drainage ditch affects the wetland assessment area (WAA). The water table slope in the WAA is assumed to mimic the wetland surface except when ditches, wells, or other alterations cause it to be modified. If a ditch is present or the stream channel has been deepened, then the lateral extent of the effect on water table slope must be determined. The van Schilfgaarde equation is used as an indicator of alteration to the water table slope by providing an approximation of the lateral effect of a ditch.

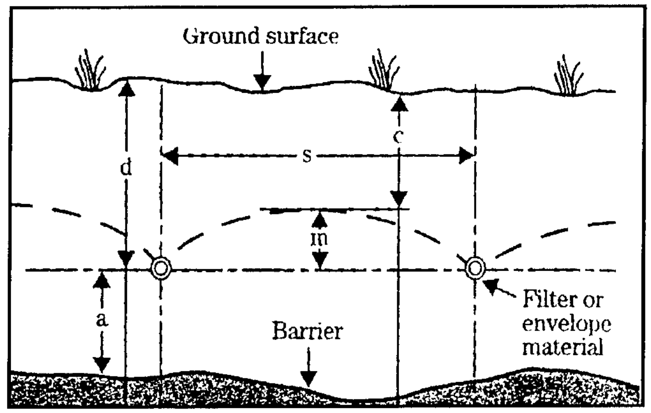


Figure C1. Parallel drain spacing (USDA NRCS 1996)

The van Schilfgaarde equation was used to determine the lateral distance (Le) over which a drainage feature would be expected to alter the water table in low-gradient riverine wetlands in western Tennessee:

$$S=2Le=\{(9KtD) / [f(\ln m_o(2D+m)-\ln m\,(2D+m_o))]\}^{1/2}$$

where

S = drain spacing distance
Le = ½ S = horizontal distance of lateral effect
K = hydraulic conductivity (distance per unit time)
t = time for water table to drop from height m_o to depth m
D = equivalent depth from drainage feature to impermeable layer
f = drainable porosity of the water-conducting soil expressed as a fraction
m_o = height of water table above the center of the drainage feature at time t = 0
m = height of water table above the center of the drainage feature at time t

Data were entered into a van Schilfgaarde equation at the ARS National Sedimentation Laboratory/NRCS Wetland Science Institute web page site: *http://msa.ars.usda.gov/ms/oxford/nsl/java/Schilfgaarde_java.html* (Figure C2). In doing so, permeability (K) and drainable porosity (f) were determined for each soil series. The program does not allow entries for f to be less than 0.01. When calculated, drainable porosity was less than 0.01; the lowest value allowed was used.

D = depth of drainage feature (ditch) in feet
f = drainable porosity varied for each soil
m_o = height of water table in feet above the center of the drainage feature at time t = 0 (in this case, m_o = d)
t = 14 days for all calculations (time in days for the water table to drop from ground level to –12 in.).

[1] References cited in this appendix are listed in the References at the end of the main text.

Agricultural Research Service

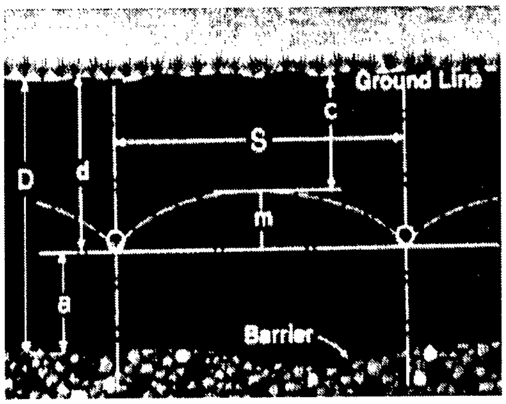
National Sedimentation Laboratory

USDA

Natural Resources Conservation Service

Wetland Science Institute

van Schilfgaarde Equation



Example tile drainage system

Input Parameters

d = ft	D = ft
f =	s = in
m_0 = ft	m = ft
t = days	Ditch (any size)
• Tile	Drain tube
D_t = select in	n = N/A in
K = in/h	Calculate **K** N/A

Intermediary Results

a = ft	d_e = ft
f ' =	r_e = ft

Final Results

S = ft	L_e = ft

Compute Reset Help About

Hydrology Tools Main Page	Ellipse Equation	Hooghoudt Equation	Kirkham's Equation

User Name : Wetland Scientist

Reset Name

Session # : 1
Time: 13:00
Date: 10/25/3901

Notes

Figure C2. van Schilfgaarde equation

D = 10 (depth to impermeable layer in feet), held constant for all calculations
S = 0.0 (surface storage), held constant for all calculations
m = d-1 (assuming regulatory criterion of soil saturation to 1 ft required to meet wetland definition (sensu Environmental Laboratory 1987)
K = hydraulic conductivity varied for each soil.

When the above parameters are entered into the ARS National Sedimentation Laboratory model, S and Le are provided as output. Lateral drainage effect distances (Le) are values provided in Table 11 in the main text and are used to determine $V_{WTSLOPE}$.

These calculations were based on the dominant conditions in the reference domain. One could calculate a more precise drainage distance (Le) for a specific soil type using soil data from a specific site.

Example:

d = variable ((40 cm (1.31 ft) – 250 cm (8.2 ft))
D = constant (10 ft)
f = variable
s = constant (0)
m_o = variable (same as d)
m = variable (d – 1 ft)
t = constant (14 days)
ditch any size
K = 1.3 for all except 1.1 for Tichnor series

K was computed as a weighted average of the top 50.8 cm (20 in.) of the soil based on the median of the range of soil permeability for each soil series.

Drainable porosity (f) was estimated using the MUUF 2.14 program. This program is available from *ftp://ftp.wcc.nrcs.usda.gov/water_mgt/muuf.*

Effective Soil Porosity

The effective porosity is the amount of pore space available for storage after adjusting for antecedent moisture conditions. Not accounting for antecedent moisture conditions or the heterogeneity of the site, the effective porosity is assumed to be equivalent to available capacity for retention of groundwater. This variable is estimated using the following relationship described by Pruitt and Nutter (unpublished manuscript):

effective porosity = total porosity - residual water content

where

effective porosity = the ratio of pore space through which water moves to the total volume of pore space available in a soil

total porosity = the percentage of soil volume occupied by pores

residual water content = the amount of water held by osmotic and capillary forces which does not freely drain from the soil and represents antecedent moisture content

Total porosity is calculated using the following relationship:

$$\text{total porosity} = 100 \times (1 - p_d / p_b)$$

where

p_d = median soil bulk density for a given soil series (g/cm^3)

p_b = particle density, g/cm^3 (assumed to be 2.65 g/cm^3)

Information on median bulk soil density (p_d) is available from bulk density ranges reported in the Physical Properties Table of County Soil Surveys or SCS Soil Interpretation Record. Particle density (p_b) is assumed to be 2.65 g/cm^3 (Fetter 1980). The information on residual water content in Table C1 is from Rawls et al. (1993).

Table C1
Residual Water Content by Soil Texture Class

Soil Texture Class	Residual Water Content, percent
Sand	2.0
Loamy sand	3.5
Sandy loam	4.1
Loam	2.7
Silt loam	1.5
Sandy clay loam	6.8
Clay loam	7.5
Silty clay loam	4.0
Sandy clay	10.9
Silty clay	5.6
Clay	9.0

Soil Texture by Feel

Clay content in soils can be measured in a laboratory by conducting a particle size analysis. However, this is often impracticable in a rapid assessment scenario. Clay content can be estimated in the field using the soil-texture-by-feel method to determine the texture class (Figure C3) and the soil texture triangle to estimate percent clay (Figure C4).

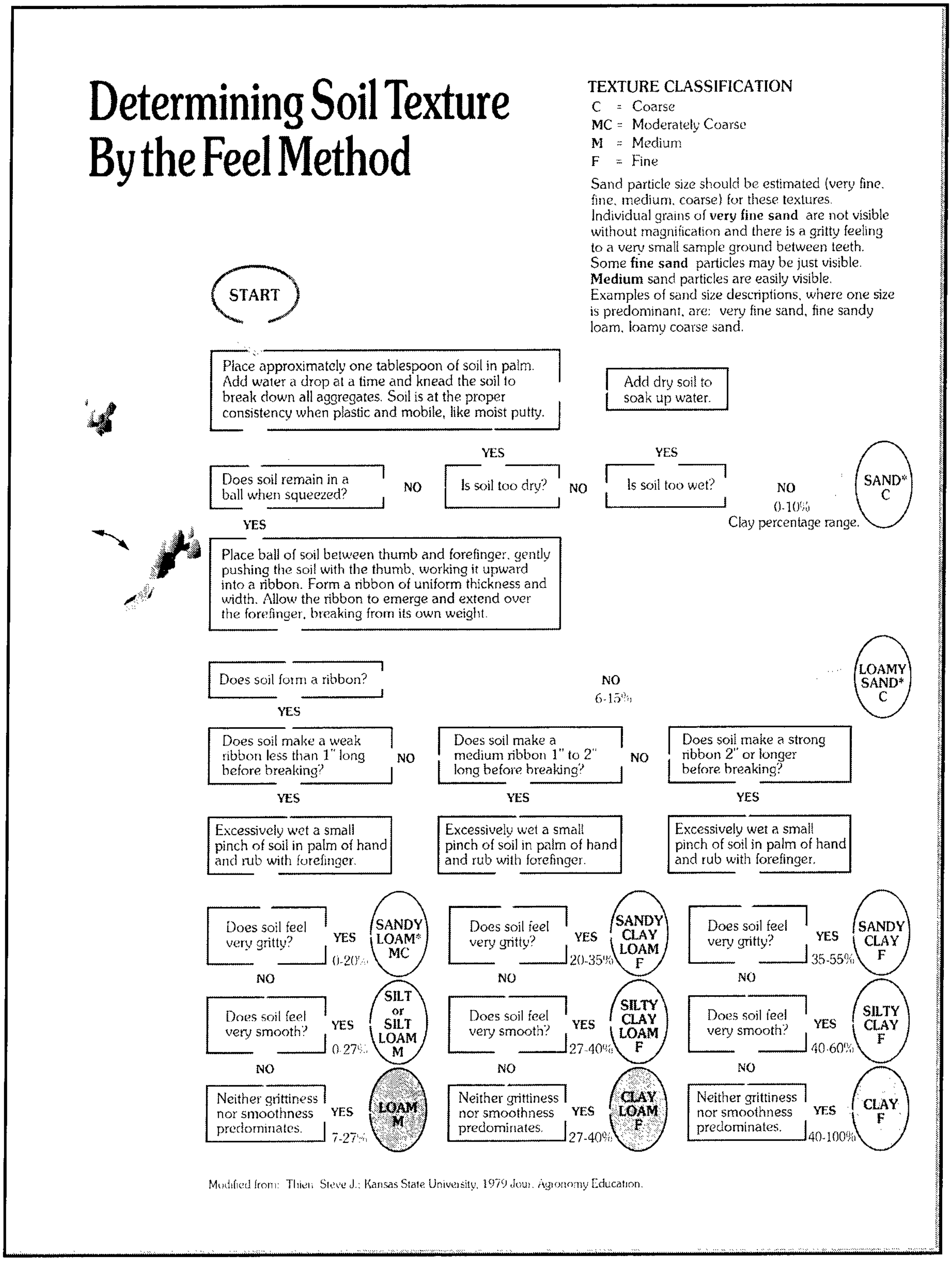


Figure C3. Estimating soil texture by "feel"

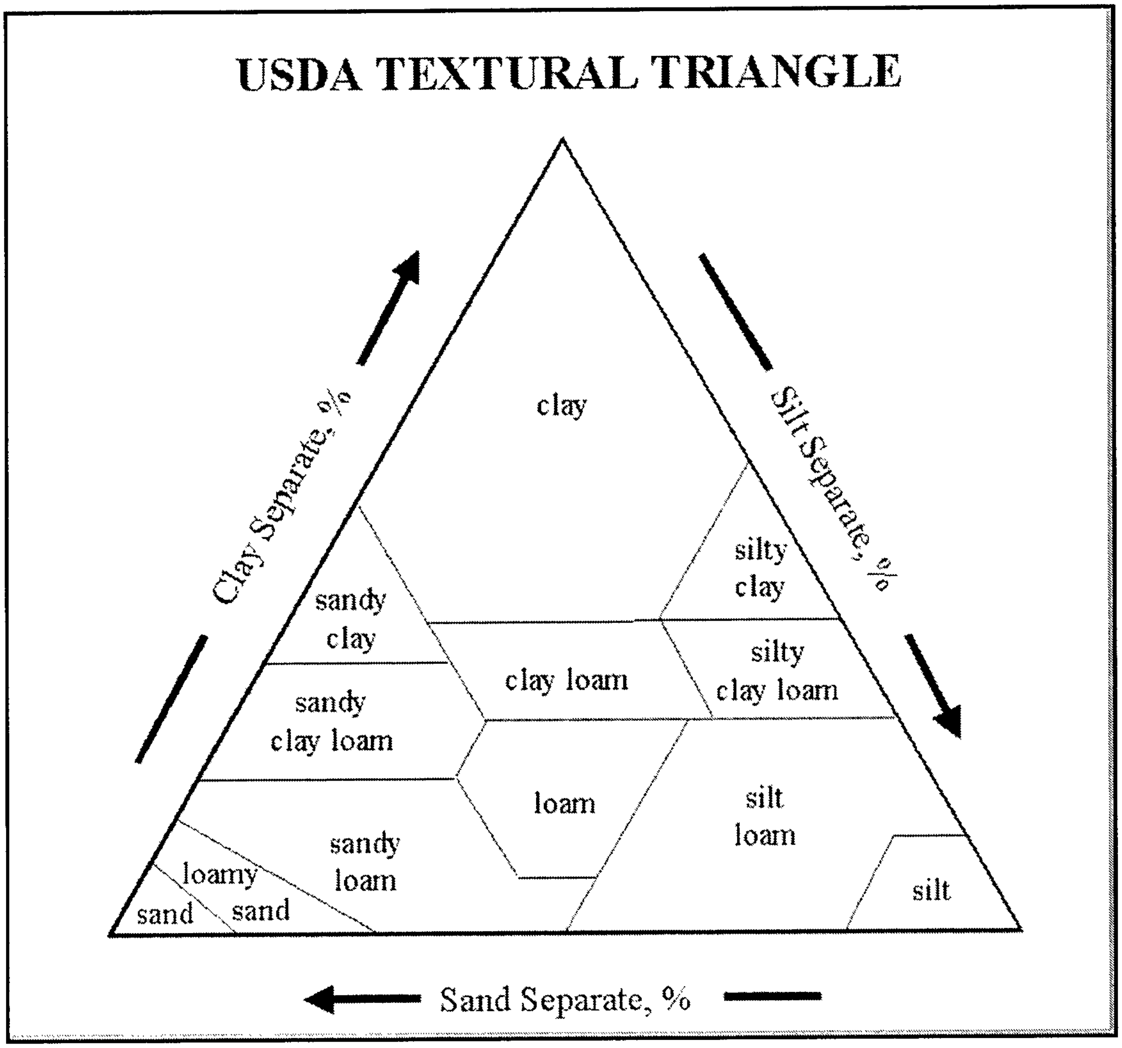


Figure C4. Soil texture triangle

Pumping Test

Soil hydraulic conductivity (soil permeability) can be directly measured using the pumping test (also referred to as a "slug" test). Freeze and Cherry (1979) describe the pumping test as a method to determine the hydraulic conductivity of a soil. In essence, this test involves the rapid removal of a known volume of water from a piezometer, causing an instantaneous change in the water level. This rapid withdrawal is sometimes accomplished by bailing the water out of the well or by using compressed air to push the water out of the well (Dawson and Istok 1991). The recovery of the water level in the well is then observed. The rate of inflow of water back into the well is then proportional to the hydraulic conductivity. The method of interpreting the water level versus time relationship that arises from these tests depends on which of two "test configurations" is considered most representative. For a more complete discussion, the end user is referred to Freeze and Cherry (1979) or Dawson and Istok (1991).

Flood Frequency Analysis Methods

The objective of determining the frequency of flooding at a particular site is to ascertain how often flood waters reach the wetland surface. This is a critical consideration in assessing the functional capacity of riverine wetlands and can be accomplished in a number of ways. In western Tennessee, however, few gages exist which are suitable for determining frequency of flooding or a range of frequencies necessary to scale the variable subindex. Instead, a fluvial geomorphic regional curve of channel cross-sectional area versus drainage area on naturally formed streams, developed by Smith and Turrini-Smith (1999), was used as a basis for comparison (Figure C5). River morphology within the reference domain should be consistent, because the physical forces controlling it (climatic and geologic factors) are the same throughout the region (Smith and Turrini-Smith 1999). Additionally, one may assume that a channel having the "right" channel size for a particular drainage area will have approximately the "right" hydrology, at least for the level of preciscion possible with these models (Personal communication, 1999, T. H. Diehl, U.S. Geological Survey, Nashville, TN). The variable subindex was scaled as magnitude of departure from the regional curve for cross-sectional area (Personal communication, 1999, T. H. Diehl, U.S. Geological Survey, Nashville, TN).

Scaling was accomplished by analyzing growing season data (March 1 to November 1) from the USGS gage at Bolivar on the Hatchie River (Table C2). The discharge at which incipient flooding begins at this location is 4,900 cfs (Personal communication, 1999, T. H. Diehl, U.S. Geological Survey, Nashville, TN). This discharge was met or exceeded in 64 out of 67 years for an average of 28 days during the growing season. A discharge of twice that, 9800 cfs, was exceeded in 42 of 67 years for an average of 5 days in a growing season. More to the point, if the channel cross-sectional area was twice as large, the floodplain would be inundated by overbank flooding for an average of 5 days during the growing season in 42 of 67 years, and if the the channel area was 4 times as large, a discharge 4 times as great (19,600 cfs) would be

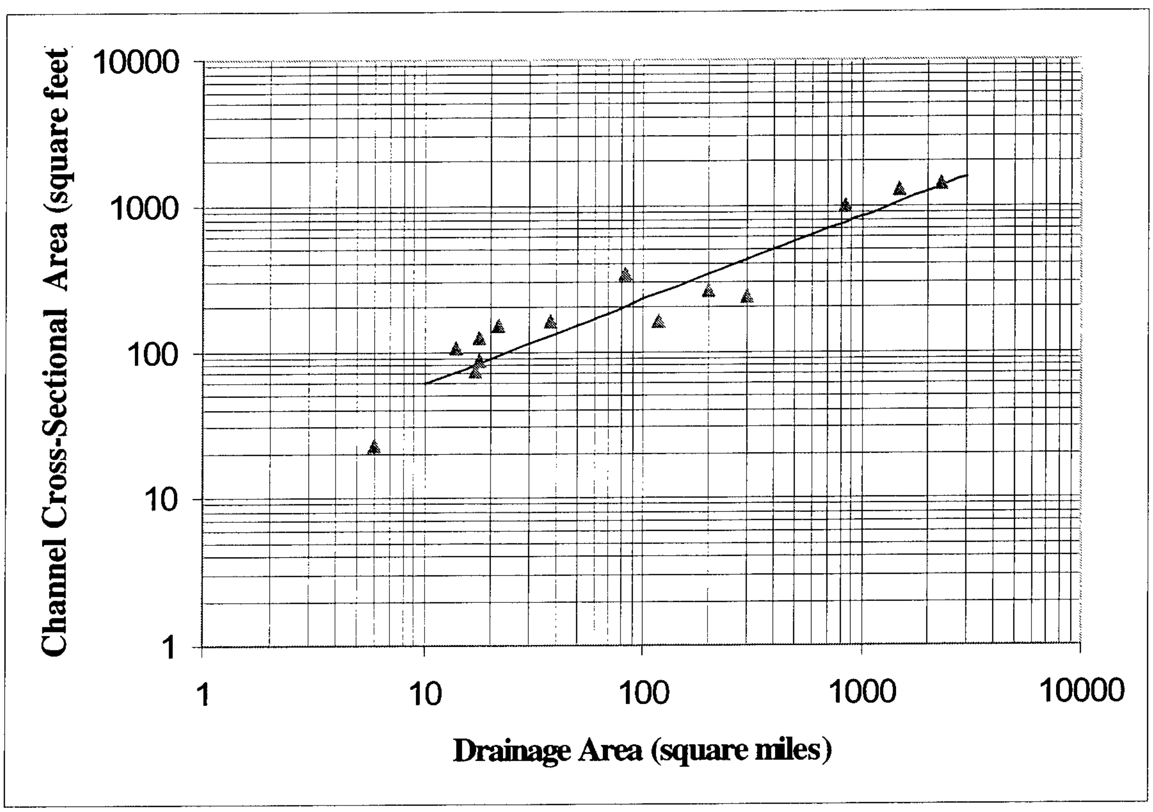


Figure C5. Channel cross-sectional area versus drainage area

Table C2
Discharge Data for the Hatchie River at Bolivar

Discharge, cfs	Average number of days meeting or exceeding this discharge during the growing season	Number of growing seasons out of 67 where this discharge was met or exceeded	Note
3,200	52	66	
4,900	28	64	point of incipient flooding (bankfull)
6,760	14	58	
8,930	7	46	
9,800	5	42	twice bankfull
17,900	1	20	
19,600	1	19	four times bankfull

required to inundate the floodplain. A discharge of this magnitude occurred in only 19 of 67 years and averaged 1 day in length. A channel four times the size of the natural channel would carry all but the largest of discharges, effectively disconnecting the river from the floodplain. Thus, the var-iable subindex is given a score of 1.0 for a channel cross-sectional area within a factor of 2 of the regional curve (also because the scatter of points used to develop the curve is close to $\pm$ a factor of 2). It is scored 0.5 for a departure factor of 2-4 from the regional curve, and 0.1 where the channel area is 4 times or greater than the regional curve.

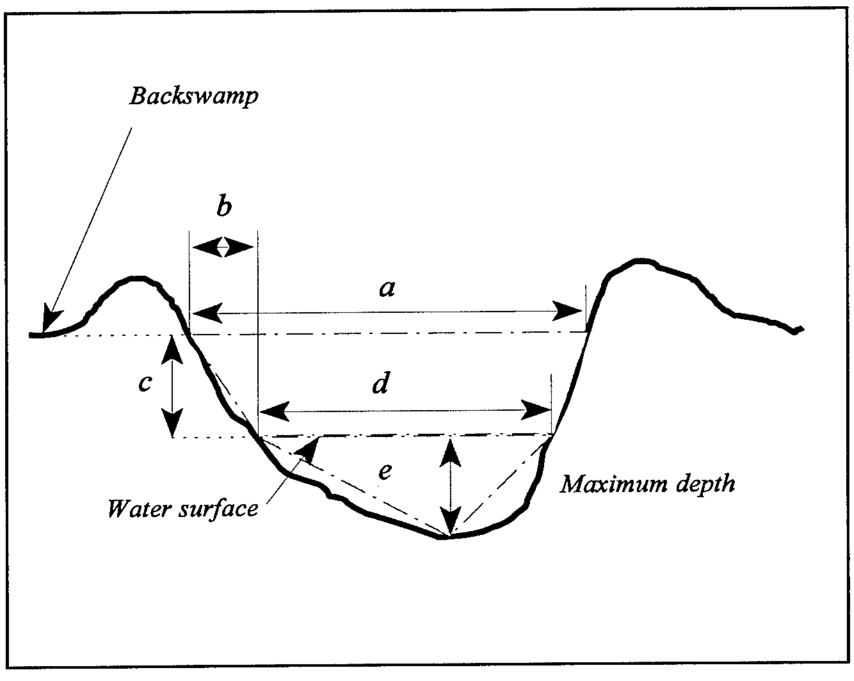


Figure C6. Five measurements on cross-sectional area

Step 1. The first step to determine channel cross-sectional area is to make a minimum of 5 measurements (Figure C6). These measurements should be taken in a straight reach of channel away from the influence of any structure, especially bridges.

a. Measure the width of the channel at the point of incipient flooding (line a in Figure C6). In western Tennes-see on streams with no levees or with natural levees, this is the width of the channel at the elevation of the backswamp (Smith and Turrini-Smith 1999). On streams with man-made levees

or spoil piles, this would be the channel width at the levee top or at any break in the levee, if higher than the backswamp.

b. Measure the horizontal distance between the point of incipient flooding and the nearest edge of the water (line b in Figure C6).

c. Measure the vertical distance between the point of incipient flooding and the water surface (line c in Figure C6).

d. Measure the width of the water surface (line d in Figure C6).

e. Measure the maximum depth of the water (line e in Figure C6).

Step 2. Calculate the area of the channel cross section.

$$A=[(b\times c)\div 2]+[d\times c]+[(a-b-d)\times c\div 2]+[(d\times e)\div 2]$$

Step 3. Determine the drainage area (DA) of the watershed above the wetland assessment area and calculate the expected channel cross section for a watershed of that size using the regression equation for channel cross-sectional area developed by Smith and Turrini-Smith (1999).

$$A=16.4\times DA^{0.57}$$

Compare the expected cross-sectional area to that calculated in Step 2. Determine the magnitude of departure from the "norm" by dividing the result in Step 2 by that in Step 3. For example, assume that the drainage area above the wetland assessment area is 100 mi^2 and the measured channel cross-sectional area is 915 ft^2. For a watershed draining 100 mi^2, the regression equation gives an expected cross-sectional area of 227 ft^2 so the channel capacity is a factor of 4 larger than that expected for a watershed of 100 mi^2 ($915 \div 227 = 4.03$). The variable subindex would be 0.1.

The assumptions of this approach are:

a. That a naturally formed channel provides a natural hydrologic regime in adjacent riverine wetlands.

b. That discharge is roughly proportional to channel cross section. In other words, if an existing channel has twice the cross-sectional area as a naturally formed channel with the same drainage area, it will carry (roughly) twice the discharge.

c. That if a discharge capable of inundating the floodplain does not occur for two weeks during the growing season (rationale based on regulatory definition), then the riverine hydrology may be considered to be impaired.

Appendix D
Reference Wetland Data

Table D1 contains the data collected at reference wetland sites in western Tennessee.

Table D1
Low-Gradient Riverine Wetlands in Western Tennessee Reference Wetland Data

	Variable Number ----->			1	2	3
	Variable Number ----->			Vtract	Vcore	Vconnect
	Metric------------------->			Size of	% of Vtract	% of Vtract
				wetland	with >300m	perimeter
				area	buffer	connected
	Units ------->			ha		
Site-Plot Name	**Description**	**Refrstnd?**	**Zone**			
Site Name	Description		Zone	1 Vtract	2 Vcore	3 Vconnect
Tigrett WMA, 1	Batteur, sapling/pole		Batteur	1542	54	0
Beech Ridge WMA	Mature Timber		Depression	5625	68	0
Gooch WMA	Mature Timber		Depression	5262	91	0
Hartsfield Road	Pole to Sawtimber		Depression	1815	0	5
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	21412	73	12
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	21412	73	12
Near Dresden	Tupelo canopy		Depression	544	53	0
Pinson Mound State Park	Mature Timber		Depression	2389	86	0
S. Bells	Buttonbush coming in under Cypress can		Depression	1724	68	0
Tigrett WMA, 2	Mature Timber		Depression	2450	84	0
Wolf at Moscow	Pole to Sawtimber		Depression	8891	62	22
Wolf River WMA	Mature Timber	yes	Depression	8891	62	22
	Pole to Sawtimber		Depression	817	55	0
Akin & Porter Oak Plantation	Shrub/Sapling		Flat	91	0	0
Beech Ridge WMA	Mature Timber		Flat	5625	68	0
Big Cypress Tree SNA	Mature Timber		Flat	5625	68	0
Fort Ridge WMA	Pole to Sawtimber		Flat	3357	45	0
Gooch WMA	Mature Timber		Flat	5262	91	0
Hartsfield Road	Pole to Sawtimber		Flat	1815	0	5
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	21412	73	12
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	21412	73	12
Horn's Bluff WMA	Sedges, grasses, forbs		Flat	181	0	0
Hwy 152 at Humboldt	Pole to sawtimber		Flat	91	0	0
Jarrell Bottoms	Pole to Sawtimber		Flat	3085	0	0
Madison County	Swamped out, buttonbush		Flat	726	2	0
Mannis Swamp WMA	Row crop field		Flat	0	0	0
Pinson Mound State Park	Mature Timber		Flat	2389	86	0
Rossville	Sawtimber		Flat	8891	62	22
S. Bells	Early Successional, Sedges, grasses, for		Flat	1724	68	0
Tigrett WMA, 1	Sawtimber, pioneer trees		Flat	1542	54	0
Tigrett WMA, 2	Pole to Sawtimber		Flat	2041.666667	70	0
Wolf River WMA	Mature Timber	yes	Flat	8891	62	22
	Timber, pioneer species		Flat	726	2	0
	Early Successional, sedges, grasses, fort		Flat	8891	62	22
	Soybean Field		Flat	8891	62	22
	Pole to Sawtimber		Flat	817	55	0
	Pole to Sawtimber		Flat	817	55	0
Beech Ridge WMA	Mature Timber		Ridge	5625	68	0
Big Cypress Tree SNA	Mature Timber		Ridge	5625	68	0
Gooch WMA	Mature Timber		Ridge	5262	91	0
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Ridge	21412	73	12
Pinson Mound State Park	Mature Timber		Ridge	2389	86	0
Wolf River WMA	Mature Timber	yes	Ridge	8891	62	22

	Variable Number ---->			4	5	6
	Variable Number ---->			Vslope	Vstore	Vmacro
	Metric------------------>			% floodplain	Ratio of	% of WAA
				slope	floodplain	with macro
					width to	topography
					channel width	
		Units ------>				
Site-Plot Name	**Description**	**Refrstnd?**	**Zone**	**Site-Plot Name**		**Description**
Site Name	Description		Zone	4 Vslope	5 Vstore	6 Vmacro
Tigrett WMA, 1	Batteur, sapling/pole		Batteur	0.03	175	10
Beech Ridge WMA	Mature Timber		Depression	0.02	83	5
Gooch WMA	Mature Timber		Depression	0.02	68	3
Hartsfield Road	Pole to Sawtimber		Depression	0.06	32	0
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	0.04	82.6	5
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	0.04	82.6	5
Near Dresden	Tupelo canopy		Depression	0.05	58	1
Pinson Mound State Park	Mature Timber		Depression	0.04	56	0
S. Bells	Buttonbush coming in under Cypress can		Depression	0.02	51	3
Tigrett WMA, 2	Mature Timber		Depression	0.03	149	1
Wolf at Moscow	Pole to Sawtimber		Depression	0.08	53	5
Wolf River WMA	Mature Timber	yes	Depression	0.04	53	5
	Pole to Sawtimber		Depression	0.01	63	3
Akin & Porter Oak Plantation	Shrub/Sapling		Flat	0.04	63	0
Beech Ridge WMA	Mature Timber		Flat	0.02	83	5
Big Cypress Tree SNA	Mature Timber		Flat	0.05	35	5
Fort Ridge WMA	Pole to Sawtimber		Flat	0.02	106	3
Gooch WMA	Mature Timber		Flat	0.02	68	3
Hartsfield Road	Pole to Sawtimber		Flat	0.06	32	0
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	0.04	82.6	5
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	0.04	82.6	5
Horn's Bluff WMA	Sedges, grasses, forbs		Flat	0.02	98	0
Hwy 152 at Humboldt	Pole to sawtimber		Flat	0.03	64	0
Jarrell Bottoms	Pole to Sawtimber		Flat	0.06	43	3
Madison County	Swamped out, buttonbush		Flat	0.01	44	2
Mannis Swamp WMA	Row crop field		Flat	0.04	103	0
Pinson Mound State Park	Mature Timber		Flat	0.04	56	0
Rossville	Sawtimber		Flat	0.06	53	4
S. Bells	Early Successional, Sedges, grasses, for		Flat	0.02	51	3
Tigrett WMA, 1	Sawtimber, pioneer trees		Flat	0.03	175	10
Tigrett WMA, 2	Pole to Sawtimber		Flat	0.03	149	0.8333333
Wolf River WMA	Mature Timber	yes	Flat	0.04	53	5
	Timber, pioneer species		Flat	0.01	44	3
	Early Successional, sedges, grasses, fort		Flat	0.04	53	5
	Soybean Field		Flat	0.04	53	5
	Pole to Sawtimber		Flat	0.01	63	3
	Pole to Sawtimber		Flat	0.01	63	3
Beech Ridge WMA	Mature Timber		Ridge	0.02	83	5
Big Cypress Tree SNA	Mature Timber		Ridge	0.05	35	5
Gooch WMA	Mature Timber		Ridge	0.02	68	3
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Ridge	0.04	82.6	5
Pinson Mound State Park	Mature Timber		Ridge	0.04	56	0
Wolf River WMA	Mature Timber	yes	Ridge	0.04	53	5

	Variable Number --->			9	10	11
	Variable Number --->			Vsoilint	Vwtf	Vwtd
	Metric------------->			% WAA	water table	depth to
				altered	fluctuations	easonal higl
						water table
	Units ------>ha					inches
Site-Plot Name	**Description**	**Refrstnd?**	**Zone**			
Tigrett WMA, 1	Batteur, sapling/pole		Batteur	0	pres	<6
Beech Ridge WMA	Mature Timber		Depression	0	pres	<6
Gooch WMA	Mature Timber		Depression	0	pres	<6
Hartsfield Road	Pole to Sawtimber		Depression	0	pres	<6
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	0	pres	<6
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	0	pres	<6
Near Dresden	Tupelo canopy		Depression	0	pres	<6
Pinson Mound State Park	Mature Timber		Depression	0	pres	<6
S. Bells	Buttonbush coming in under Cypress can		Depression	0	pres	<6
Tigrett WMA, 2	Mature Timber		Depression	0	pres	<6
Wolf at Moscow	Pole to Sawtimber		Depression	0	pres	<6
Wolf River WMA	Mature Timber	yes	Depression	0	pres	<6
	Pole to Sawtimber		Depression	0	pres	28
Akin & Porter Oak Plantation	Shrub/Sapling		Flat	0	pres	<6
Beech Ridge WMA	Mature Timber		Flat	0	pres	<6
Big Cypress Tree SNA	Mature Timber		Flat	0	pres	<6
Fort Ridge WMA	Pole to Sawtimber		Flat	0	pres	<6
Gooch WMA	Mature Timber		Flat	0	pres	<6
Hartsfield Road	Pole to Sawtimber		Flat	0	pres	<6
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	0	pres	<6
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	0	pres	<6
Horn's Bluff WMA	Sedges, grasses, forbs		Flat	100	pres	<6
Hwy 152 at Humboldt	Pole to sawtimber		Flat	0	pres	<6
Jarrell Bottoms	Pole to Sawtimber		Flat	25	pres	<6
Madison County	Swamped out, buttonbush		Flat	0	pres	-36
Mannis Swamp WMA	Row crop field		Flat	100	pres	<6
Pinson Mound State Park	Mature Timber		Flat	0	pres	<6
Rossville	Sawtimber		Flat	0	pres	<6
S. Bells	Early Successional, Sedges, grasses, for		Flat	0	pres	<6
Tigrett WMA, 1	Sawtimber, pioneer trees		Flat	0	pres	<6
Tigrett WMA, 2	Pole to Sawtimber		Flat	0	pres	<6
Wolf River WMA	Mature Timber	yes	Flat	0	pres	<6
	Timber, pioneer species		Flat	0	pres	<6
	Early Successional, sedges, grasses, fort		Flat	0	pres	<6
	Soybean Field		Flat	100	pres	<6
	Pole to Sawtimber		Flat	0	absent	28
	Pole to Sawtimber		Flat	0	absent	28
Beech Ridge WMA	Mature Timber		Ridge	0	pres	<6
Big Cypress Tree SNA	Mature Timber		Ridge	0	pres	<6
Gooch WMA	Mature Timber		Ridge	0	pres	<6
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Ridge	0	pres	<6
Pinson Mound State Park	Mature Timber		Ridge	0	pres	<6
Wolf River WMA	Mature Timber	yes	Ridge	0	pres	<6

				15	16	17
		Variable Number ---->		Vsurfcon	Vclay	Vredox
		Metric-------------->		% stream	% WAA with	redoximorpl
				reach with	altered clay	features
				altered	content	present (1)
				connections		absent (0)
		Units ------->ha				
Site-Plot Name	Description	Refrstnd?	Zone			
Tigrett WMA, 1	Batteur, sapling/pole		Batteur	45	0	pres
Beech Ridge WMA	Mature Timber		Depression	15	0	pres
Gooch WMA	Mature Timber		Depression	0	0	pres
Hartsfield Road	Pole to Sawtimber		Depression		0	pres
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	0	0	pres
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	0	0	pres
Near Dresden	Tupelo canopy		Depression		0	pres
Pinson Mound State Park	Mature Timber		Depression	85	0	pres
S. Bells	Buttonbush coming in under Cypress can		Depression		0	pres
Tigrett WMA, 2	Mature Timber		Depression	45	0	pres
Wolf at Moscow	Pole to Sawtimber		Depression		0	pres
Wolf River WMA	Mature Timber	yes	Depression	0	0	pres
	Pole to Sawtimber		Depression		0	pres
Akin & Porter Oak Plantation	Shrub/Sapling		Flat		0	pres
Beech Ridge WMA	Mature Timber		Flat	15	0	pres
Big Cypress Tree SNA	Mature Timber		Flat	70	0	pres
Fort Ridge WMA	Pole to Sawtimber		Flat	100	0	pres
Gooch WMA	Mature Timber		Flat	0	0	pres
Hartsfield Road	Pole to Sawtimber		Flat		0	pres
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	0	0	pres
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	0	0	pres
Horn's Bluff WMA	Sedges, grasses, forbs		Flat		0	pres
Hwy 152 at Humboldt	Pole to sawtimber		Flat	100	0	pres
Jarrell Bottoms	Pole to Sawtimber		Flat	0	0	pres
Madison County	Swamped out, buttonbush		Flat	100	0	pres
Mannis Swamp WMA	Row crop field		Flat		0	pres
Pinson Mound State Park	Mature Timber		Flat	85	0	pres
Rossville	Sawtimber		Flat	30	0	pres
S. Bells	Early Successional, Sedges, grasses, for		Flat		0	pres
Tigrett WMA, 1	Sawtimber, pioneer trees		Flat	45	0	pres
Tigrett WMA, 2	Pole to Sawtimber		Flat	45	0	pres
Wolf River WMA	Mature Timber	yes	Flat	0	0	pres
	Timber, pioneer species		Flat		0	pres
	Early Successional, sedges, grasses, fort		Flat		0	pres
	Soybean Field		Flat		0	pres
	Pole to Sawtimber		Flat		0	pres
	Pole to Sawtimber		Flat		0	pres
Beech Ridge WMA	Mature Timber		Ridge	15	0	pres
Big Cypress Tree SNA	Mature Timber		Ridge	70	0	pres
Gooch WMA	Mature Timber		Ridge	0	0	pres
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Ridge	0	0	pres
Pinson Mound State Park	Mature Timber		Ridge	85	0	pres
Wolf River WMA	Mature Timber	yes	Ridge	0	0	pres

		Variable Number ----->		18	19	20
		Variable Number ----->		Vtba	Vtden	Vsnag
		Metric--------------->		tree	tree density	snag
				basal		density
				area		
		Units ------>ha		m2 / ha	stems / ha	stems / ha
Site-Plot Name	Description	Refrstnd?	Zone			
Tigrett WMA, 1	Batteur, sapling/pole		Batteur	5	292	8
Beech Ridge WMA	Mature Timber		Depression	68	794	75
Gooch WMA	Mature Timber		Depression	52	750	25
Hartsfield Road	Pole to Sawtimber		Depression	28	642	50
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	58	663	56
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	28	725	25
Near Dresden	Tupelo canopy		Depression	48	600	50
Pinson Mound State Park	Mature Timber		Depression	65	706	38
S. Bells	Buttonbush coming in under Cypress can		Depression	15	350	0
Tigrett WMA, 2	Mature Timber		Depression	49	663	13
Wolf at Moscow	Pole to Sawtimber		Depression	21	1150	25
Wolf River WMA	Mature Timber	yes	Depression	56	1110	95
	Pole to Sawtimber		Depression	31	825	75
Akin & Porter Oak Plantation	Shrub/Sapling		Flat	0	0	0
Beech Ridge WMA	Mature Timber		Flat	42	560	55
Big Cypress Tree SNA	Mature Timber		Flat	29	410	10
Fort Ridge WMA	Pole to Sawtimber		Flat	22	625	20
Gooch WMA	Mature Timber		Flat	35	430	45
Hartsfield Road	Pole to Sawtimber		Flat	24	638	25
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	29	436	33
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	34	725	100
Horn's Bluff WMA	Sedges, grasses, forbs		Flat	6	225	13
Hwy 152 at Humboldt	Pole to sawtimber		Flat	25	513	63
Jarrell Bottoms	Pole to Sawtimber		Flat	17	588	44
Madison County	Swamped out, buttonbush		Flat	1	33	133
Mannis Swamp WMA	Row crop field		Flat	0	0	0
Pinson Mound State Park	Mature Timber		Flat	42	450	15
Rossville	Sawtimber		Flat	33	908	33
S. Bells	Early Successional, Sedges, grasses, for		Flat	9	213	38
Tigrett WMA, 1	Sawtimber, pioneer trees		Flat	29	694	106
Tigrett WMA, 2	Pole to Sawtimber		Flat	21	358	29
Wolf River WMA	Mature Timber	yes	Flat	33	450	33
	Timber, pioneer species		Flat	26	950	25
	Early Successional, sedges, grasses, fort		Flat	0	0	0
	Soybean Field		Flat	0	0	0
	Pole to Sawtimber		Flat	31	825	0
	Pole to Sawtimber		Flat	36	825	0
Beech Ridge WMA	Mature Timber		Ridge	39	410	30
Big Cypress Tree SNA	Mature Timber		Ridge	37	380	20
Gooch WMA	Mature Timber		Ridge	46	380	30
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Ridge	43	283	25
Pinson Mound State Park	Mature Timber		Ridge	29	395	30
Wolf River WMA	Mature Timber	yes	Ridge	33	355	20

				21	22	23
		Variable Number ----->		Vwd	Vlog	Vssd
		Metric------------->		volume of	volume of	shrub and
				woody debris	logs	sapling den:
		Units ------>ha		m3 / ha	m3 / ha	stems / ha
Site-Plot Name	Description	Refrstnd?	Zone			
Tigrett WMA, 1	Batteur, sapling/pole		Batteur	42	0	4867
Beech Ridge WMA	Mature Timber		Depression	52	472	425
Gooch WMA	Mature Timber		Depression	40	0	325
Hartsfield Road	Pole to Sawtimber		Depression	215	49	933
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	44	140	313
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	412	97	1025
Near Dresden	Tupelo canopy		Depression	375	88	2413
Pinson Mound State Park	Mature Timber		Depression	41	0	356
S. Bells	Buttonbush coming in under Cypress can		Depression	16	0	1725
Tigrett WMA, 2	Mature Timber		Depression	356	79	875
Wolf at Moscow	Pole to Sawtimber		Depression	77	8	1425
Wolf River WMA	Mature Timber	yes	Depression	35	121	20
	Pole to Sawtimber		Depression	155	30	2750
Akin & Porter Oak Plantation	Shrub/Sapling		Flat	0	0	4600
Beech Ridge WMA	Mature Timber		Flat	22	0	1025
Big Cypress Tree SNA	Mature Timber		Flat	53	0	540
Fort Ridge WMA	Pole to Sawtimber		Flat	53	15	1795
Gooch WMA	Mature Timber		Flat	53	0	560
Hartsfield Road	Pole to Sawtimber		Flat	229	54	513
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	44	0	769
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat			1475
Horn's Bluff WMA	Sedges, grasses, forbs		Flat	22	3	4929
Hwy 152 at Humboldt	Pole to sawtimber		Flat	235	58	600
Jarrell Bottoms	Pole to Sawtimber		Flat	33	5	2013
Madison County	Swamped out, buttonbush		Flat	22	477	24833
Mannis Swamp WMA	Row crop field		Flat	0	0	5125
Pinson Mound State Park	Mature Timber		Flat	92	792	195
Rossville	Sawtimber		Flat	65	10	1025
S. Bells	Early Successional, Sedges, grasses, for		Flat	50	11	350
Tigrett WMA, 1	Sawtimber, pioneer trees		Flat	78	346	544
Tigrett WMA, 2	Pole to Sawtimber		Flat	452	113	8517
Wolf River WMA	Mature Timber	yes	Flat	75	42	621
	Timber, pioneer species		Flat	82	7	925
	Early Successional, sedges, grasses, fort		Flat	0	0	0
	Soybean Field		Flat	0	0	4800
	Pole to Sawtimber		Flat	87	18	2400
	Pole to Sawtimber		Flat	258	51	1375
Beech Ridge WMA	Mature Timber		Ridge	55	488	1250
Big Cypress Tree SNA	Mature Timber		Ridge	26	166	1140
Gooch WMA	Mature Timber		Ridge	37	379	1315
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Ridge	19	0	1179
Pinson Mound State Park	Mature Timber		Ridge	49	0	785
Wolf River WMA	Mature Timber	yes	Ridge	25	0	840

	Variable Number ---->			24	25	26	27
	Variable Number ---->			Vgvc	Vohor	Vahor	Vcomp
	Metric----------------->			% cover ground vegetation	% cover of O soil horizon	% cover of A soil horizon	% concurrence with dominant plant species
	Units ------>ha						
Site-Plot Name	**Description**	**Refrstnd?**	**Zone**				
Tigrett WMA, 1	Batteur, sapling/pole		Batteur	17	45	100	
Beech Ridge WMA	Mature Timber		Depression	10	99	100	39
Gooch WMA	Mature Timber		Depression	6	89	100	28
Hartsfield Road	Pole to Sawtimber		Depression	21	29	100	19
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	2	15	100	100
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Depression	14	18	100	100
Near Dresden	Tupelo canopy		Depression	10	28	100	19
Pinson Mound State Park	Mature Timber		Depression	5	30	100	30
S. Bells	Buttonbush coming in under Cypress can		Depression	23	23	100	19
Tigrett WMA, 2	Mature Timber		Depression	29	71	100	19
Wolf at Moscow	Pole to Sawtimber		Depression	16	79	100	8
Wolf River WMA	Mature Timber	yes	Depression	4	1	100	100
	Pole to Sawtimber		Depression	20	57	100	0
Akin & Porter Oak Plantation	Shrub/Sapling		Flat	100	96	100	8
Beech Ridge WMA	Mature Timber		Flat	29	94	100	33
Big Cypress Tree SNA	Mature Timber		Flat	28	92	100	25
Fort Ridge WMA	Pole to Sawtimber		Flat	27	88	100	11
Gooch WMA	Mature Timber		Flat	32	78	100	25
Hartsfield Road	Pole to Sawtimber		Flat	53	49	100	0
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	8	61	100	100
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Flat	12	27	100	100
Horn's Bluff WMA	Sedges, grasses, forbs		Flat	82	36	100	0
Hwy 152 at Humboldt	Pole to sawtimber		Flat	72	42	100	11
Jarrell Bottoms	Pole to Sawtimber		Flat	15	50	100	20
Madison County	Swamped out, buttonbush		Flat	84	0	100	0
Mannis Swamp WMA	Row crop field		Flat	48	21	100	0
Pinson Mound State Park	Mature Timber		Flat	26	71	100	35
Rossville	Sawtimber		Flat	39	42	100	11
S. Bells	Early Successional, Sedges, grasses, for		Flat	76	77	100	0
Tigrett WMA, 1	Sawtimber, pioneer trees		Flat	7	94	100	5
Tigrett WMA, 2	Pole to Sawtimber		Flat	30	61	100	7
Wolf River WMA	Mature Timber	yes	Flat	42	80	100	100
	Timber, pioneer species		Flat	39	90	100	0
	Early Successional, sedges, grasses, for		Flat	8	12	100	8
	Soybean Field		Flat	88	96	100	8
	Pole to Sawtimber		Flat	76	86	100	5
	Pole to Sawtimber		Flat	26	52	100	5
Beech Ridge WMA	Mature Timber		Ridge	29	99	100	
Big Cypress Tree SNA	Mature Timber		Ridge	53	97	100	
Gooch WMA	Mature Timber		Ridge	46	97	100	
Hatchie National Wildlife Refuge, ab	Mature Timber	yes	Ridge	27	96	100	100
Pinson Mound State Park	Mature Timber		Ridge	75	88	100	100
Wolf River WMA	Mature Timber	yes	Ridge	46	97	100	100

LOW-GRADIENT RIVERINE WETLANDS IN WESTERN TENNESSEE

A-TEAM LEADER/COORDINATOR

Name: Mr. Timothy C. Wilder
Address: Tennessee Department of Environment and Conservation
2484 Park Plus Drive
Columbia, TN 38401
Phone: 931-840-4170
Fax: 931-380-3397
E-mail: twilder@mail.state.tn.us

and

Name: Dr. Thomas H. Roberts
Address: Tennessee Technological University
P.O. Box 5063
Cookeville, TN 38505
Phone: 931-372-3138
Fax: 931-372-6257
E-mail: troberts@tntech.edu

A-TEAM MEMBERS

Name	Phone	Fax	E-mail	Organization
Patty Coffey	615-736-5026	615-7362159	Patricia.L. Coffey@ LRN01.usace. Army.mil	USACE, Nashville
Tim Davis	901-544-3471	901-544-3266	davist@usace. army.mil	USACE, Memphis
Dan Eager	615-532-0708	615-532-0046	deagar@mail. state.tn.us	Tennessee Dept. Envir. and Conserv.
Ray Hedrick	615-736-5026	615-736-2159	Ray.d.Hedrick@ usace.army.mil	USACE, Nashville
Joe Hopper	615-781-6610	615-781-4606	jhopper@mail. state.tn.us	Tennessee Wildl. Res. Agency
Mike Lee	615-532-0712	615-532-0046	mlee@mail. State.tn.us	Tennessee Dept. Envir. and Conserv.

Wade Whittinghill	615-736-5181	615-736-7145	keith.w.whittinghi ll.@usace. army.mil	USACE, Nashville
Doug Winford	931-528-6481	931-528-5075	douglas_winford @fws.gov	U.S. Fish and Wildl. Serv.
Mike Zeman	615-736-7241	615-736-7764	mzeman@tn. nrcs.usda.gov	Natural. Resour. Conserv. Serv.

Engineer Research and Development Center Point of Contact

Name	Phone	FAX	E-mail
Dan Smith	601-634-2718	601-634-2718	smithr1@wes.army. mil

Project Location

Western Tennessee Loess Plain ecoregion including all or portions of the following counties: Shelby, Tipton, Lauderdale, Dyer, Obion, Weakley, Gibson, Crockett, Haywood, Fayette, Hardeman, and Madison.
Corps Districts: Memphis
EPA Region: 4

Description of Regional Subclass

Class: Riverine
Subclass: Low gradient, fine sediment, forested, on ....

Description: This subclass typically is associated with low-gradient (less than 2% slope) 2nd - 4th order streams. There are several potential water sources though including: (a) direct precipitation, (b) lateral surface water from overbank flow, (c) lateral surface from adjacent uplands, and (d) groundwater discharge. In unmodified systems, this subclass experiences overbank events at least once a year. During overflow events, the subclass serves to provide storage and, because the streams typically carry high suspended sediment loads, retain considerable particulate matter. Another major function performed by the subclass is the provision of habitat for wildlife, fish, and a myriad of invertebrate organisms. Because of the fertile soils and plentiful moisture, biomass production is high. The subclass mediates biochemical activity including the cycling of nutrients.

The predominant natural stream type is classified as E6 (Rosgen 1994). The rivers in the reference domain have sand and silt bottoms and floodplains that are flat and wide. Historically the rivers had a slope of less than 0.0007 and meandered through straight valleys (Ashley 1910). This historical meandering produced alternating ridges and swales that were in a constant state of change, thus the floodplain surfaces are complex. Most of the major rivers and streams have been altered by channelization and levee construction and commonly are entrenched.

The natural vegetation in the reference domain is dominated by flood tolerant oaks including overcup oak (*Quercus lyrata*), willow oak (*Q. phellos*), water oak (*Q. nigra*),

swamp chestnut oak (*Q. michauxii*), cherrybark oak (*Q. pagodaefolia*), pignut hickory (*Carya glabra*), sweetgum (*Liquidambar styraciflua*), green ash (*Fraxinus pennsylvanica*), water tupelo (*Nyssa aquatica*), balcypress (*Taxodium distichum*), American hornbeam (*Carpinus caroliniana*), and slippery elm (*Ulmus rubra*).

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Tennessee Department of Environment and Conservation
Water Pollution Control
2484 Park Plus Drive
Columbia, TN 38401

Tennessee Technological University
Biology Department
P.O. Box 5063
Cookeville, TN 38505

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14. ABSTRACT

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified including: determining minimal effects under the Food Security Act, designing mitigation projects, and managing wetlands.

This report uses the HGM Approach to develop a Regional Guidebook for assessing the functions of low-gradient riverine wetlands in western Tennessee. The report begins with a characterization of low-gradient riverine wetlands in the western Tennessee, then discusses (a) the rationale used to select functions, (b) the rationale used to select model variables and metrics, (c) the rational used to develop assessment models, and (d) the data from reference wetlands used to calibrate model variables and assessment models. Finally, it outlines an assessment protocol for using the model variables and functional indices to assess low-gradient riverine wetlands in western Tennessee.

15. SUBJECT TERMS
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